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New Nouveau Brunswick

Mineral Resource Report

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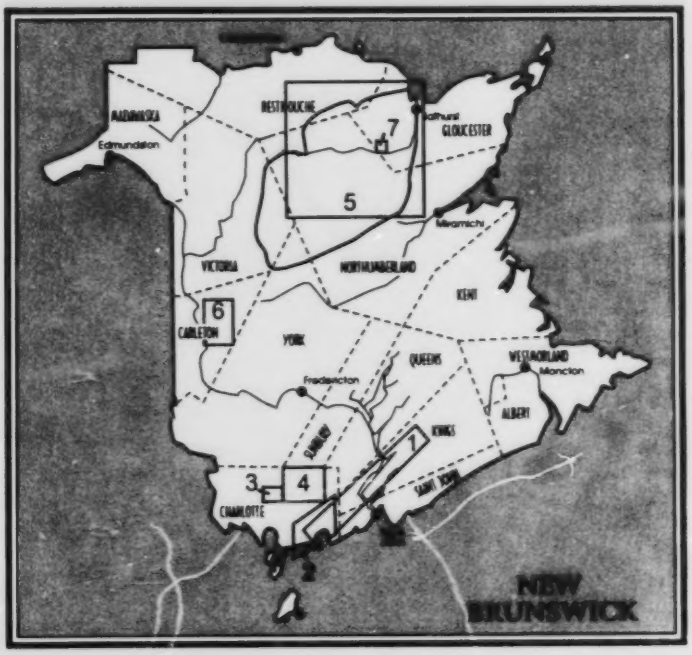

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2. Cambrian granitoid plutons, Pocologan area (Barr, White, Miller)
3. Humus, B-horizon and till data, Clarence Stream property (Friske, McCurdy, Day, McNeil)
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Bathurst Mining Camp

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† New Brunswick Geological Surveys Branch ordinary budget

†† New Brunswick Geological Surveys Branch ordinary budget and a research grant to S.M. Barr from NSERC

‡ Geological Survey of Canada ordinary budget

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THE KINGSTON GROUP: A REDEFINED SILURIAN STRATIGRAPHIC UNIT IN SOUTHERN NEW BRUNSWICK †

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BARR, S.M. and WHITE, C.E. 2001. The Kingston Group: A redefined Silurian stratigraphic unit in southern New Brunswick. *In* Current Research 2000. *Compiled by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 1–14.

The Kingston terrane of southern New Brunswick consists mainly of Silurian metavolcanic and granitoid rocks intruded by abundant mafic sheets. The metavolcanic rocks, together with minor interbedded epiclastic metasedimentary rocks, are assigned to the Kingston Group. The Kingston Group is divided into five formations composed dominantly of rhyolitic to dacitic lithic and lithic-crystal, crystal lapilli tuff, and less abundant flows, as well as basaltic and andesitic tuff and flows, and minor interbedded epiclastic wacke and siltstone. The sequence youngs to the northwest, with a total estimated maximum thickness of ca.10 km. Both the bottom and top of the sequence are major brittle faults.

Le terrane de Kingston dans le Sud du Nouveau-Brunswick est principalement constitué de roches granitiques et métavolcaniques du Silurien pénétrées par une abondance de nappes mafiques. Les roches métavolcaniques, tout comme la petite quantité de rôches métasédimentaires épiclastiques interlitées présentes ont été rattachées au groupe de Kingston. Ce dernier est subdivisé en cinq formations principalement composées de conglomérat volcanique à lapilli pyroclastique rhyolitique à dacitique lithique et cristallin et de coulées moins abondantes, ainsi que de tuf et de coulées basaltiques et andésitiques, et d'une quantité restreinte de siltstone et de wacke épiclastique interlités. La séquence devient plus jeune au nord-ouest, avec une épaisseur maximale totale estimative d'une dizaine de kilomètres. Le fond et le sommet de la séquence constituent tous deux des failles cassantes importantes.

INTRODUCTION

Southern New Brunswick consists of northeast-trending belts of contrasting pre-Devonian rocks, separated by major faults (Figure 1). The Kingston terrane, located between the Kennebecasis fault on the southeast and the Belleisle fault on the northwest, consists of Silurian metavolcanic and minor metasedimentary rocks, intruded by comagmatic granitic plutons and mafic sheets (Barr *et al.* 1997, 1999). Based on recent mapping and petrographic study, the metavolcanic and metasedimentary rocks have been divided into five formations, collectively termed the Kingston Group (Barr and White 2001). The purpose of this

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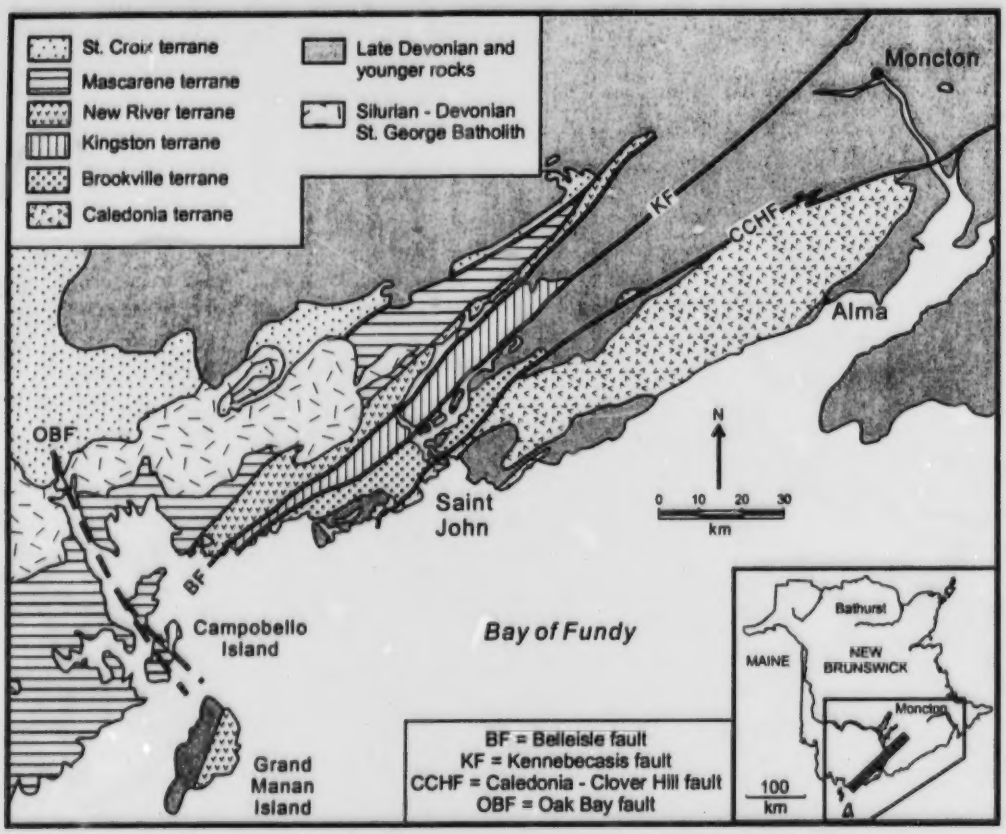

Figure 1. Terranes in southern New Brunswick, showing the location of the Kingston terrane between the Belleisle and Kennebecasis faults. Inset outline map of New Brunswick map shows the location of the Kingston terrane (shaded) and the area of Figure 1 (box).

paper is to show how the understanding of the geology of the Kingston terrane has evolved as a result of mapping, petrographic studies, and precise geochronology. In addition, the characteristic rock types in each of the new formations are described, and the locations of potential type sections are suggested. Other details about the units, including petrochemistry and results of U–Pb dating, have been or will be published elsewhere.

GEOLOGICAL SETTING

Rocks of the Kingston terrane are exposed over a distance of more than 75 km in southern New Brunswick, from Deadmans Head through Beaver Harbour and Loch Alva, across the Saint John River, and through the Kingston Peninsula to the Peekaboo Corner area (Figures 2 and 3). On the northeast they are unconformably overlain by Late Devonian to Carboniferous units; however, a strong magnetic signature associated wi' the terrane continues to the northeast across the Northumberland Strait (e.g., Miles *et al.* 2000). To the southwest, the magnetic signature can be traced offshore toward Campobello Island (Figure 1), where felsic volcanic and sedimentary units have been correlated with those of the Kingston

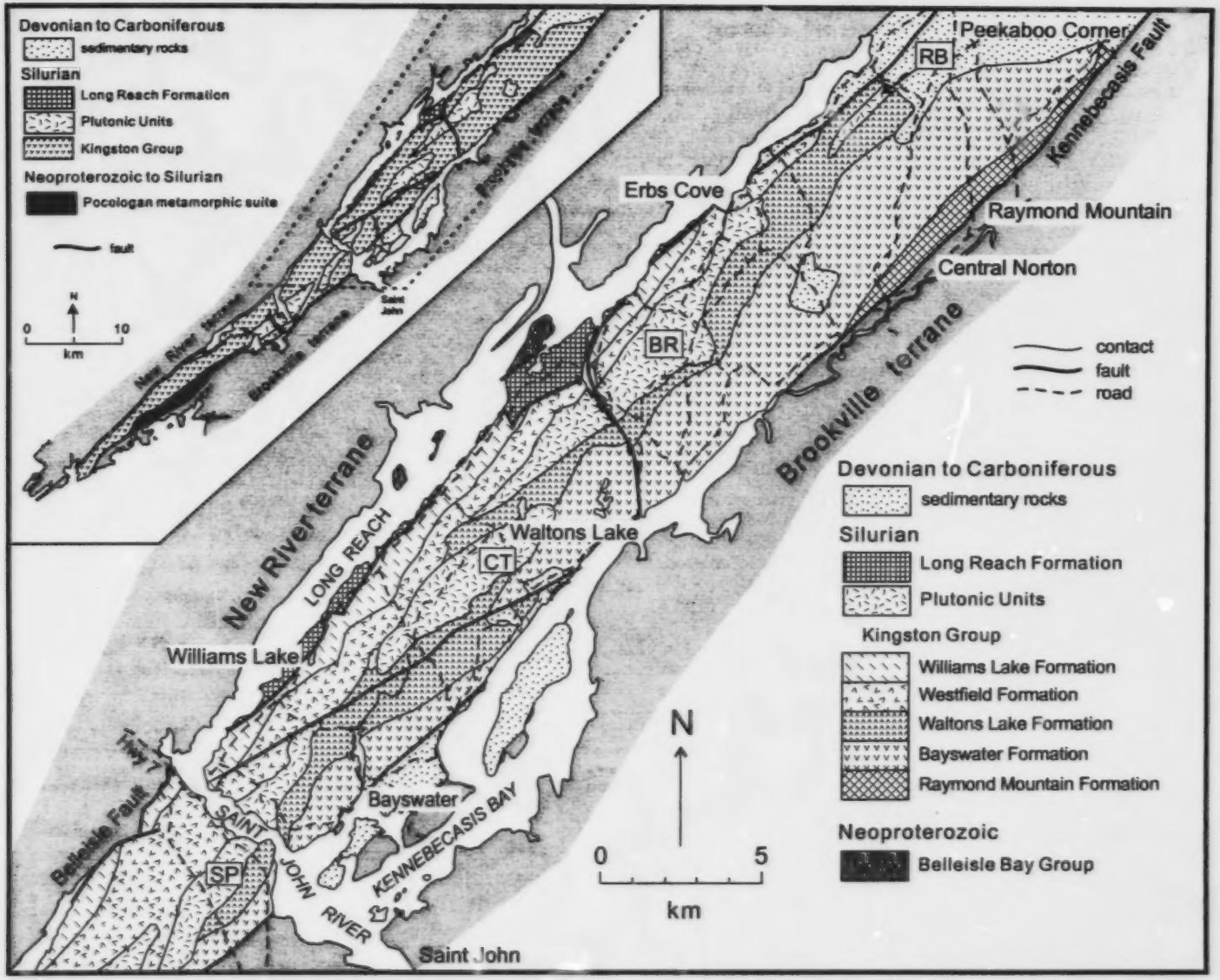

Figure 2. Simplified geological map of the northeastern part of the Kingston terrane based on the present study. Dashed box on the inset map shows approximately the part of the Kingston terrane covered by the map. Abbreviations: **SP**, Sand Point pluton; **CT**, Centreton Pluton; **BR**, Bradley Brook pluton; **RB**, Redden Brook pluton.

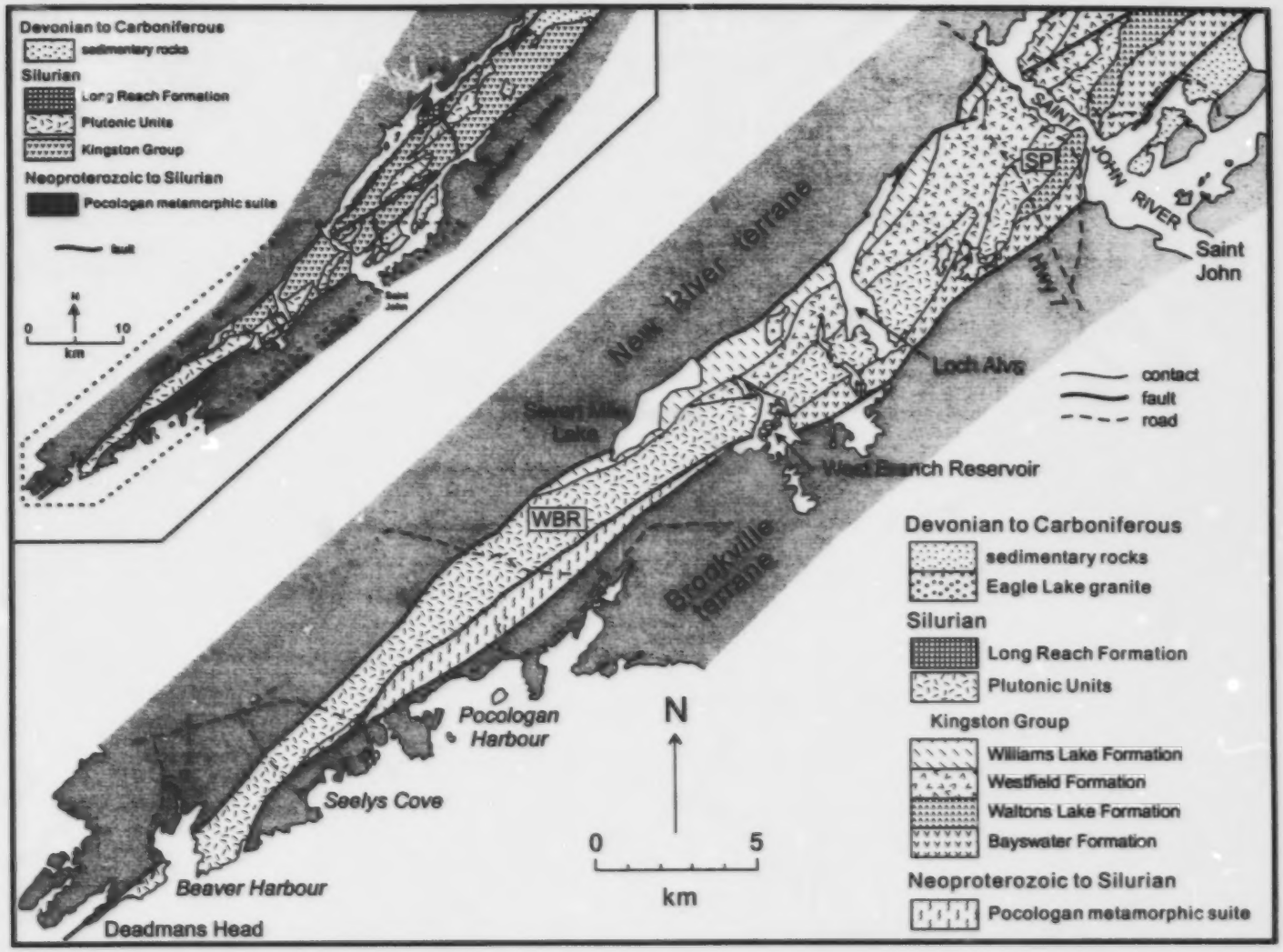

Figure 3. Simplified geological map of the southwestern part of the Kingston terrane based on the present study. Dashed box on the inset map shows approximately the part of the Kingston terrane covered by the map. Abbreviations: **WBR**, West Branch Reservoir pluton; **SP**, Sand Point pluton.

terrane (McLeod and Rast 1988). The volcanic and sedimentary units on Campobello Island appear to be locally in stratigraphic contact with mafic volcanic and turbiditic sedimentary rocks of the Silurian Quoddy Formation, which may overlie the Kingston Group (M. McLeod, personal communication, 1999).

On its southeastern margin, rocks of the Kingston terrane are in faulted contact with mainly Precambrian metamorphic and plutonic rocks of the Brookville terrane (Figure 1). The boundary is marked by a brittle fault (Kennebecasis fault) in the northeast, but southwest of the West Branch Reservoir, the position of the boundary becomes less clear because of the presence of the Pocologan metamorphic suite, a belt of mylonitic and high-grade metamorphic rocks of uncertain age and affinity (Figure 3). The Pocologan metamorphic suite appears to be separated by brittle faults from both Kingston terrane rocks to the northwest and mylonitic and nonmylonitic granitoid rocks of the Brookville terrane to the southeast (Figure 1).

The northwestern margin of the Kingston terrane is marked by the Belleisle fault (Figure 1). Through the Kingston Peninsula, volcanic and sedimentary rocks of the Long Reach Formation occur northwest of the Belleisle fault (McCutcheon and Ruitenberg 1987; McLeod *et al.* 1994). Although also Silurian in age based on fossil evidence (Boucot *et al.* 1966), the Long Reach Formation is unmetamorphosed and relatively undeformed, in contrast to the rocks of the Kingston terrane (Barr *et al.* 1997). Southwest of Highway 7, Neoproterozoic granitoid and volcanic rocks of the New River terrane (Johnson and McLeod 1996; Currie and McNicholl 1999) are juxtaposed against the Kingston terrane along the Belleisle fault (Figures 2 and 3). The New River terrane units are protomylonitic and cataclased adjacent to the fault in the Seven Mile Lake area (Seven Mile Lake mylonite zone of Garnett and Brown 1973). In contrast, rocks of the Kingston terrane do not appear to be as strongly deformed, and sedimentary structures are well preserved in outcrops around the southern shore of Seven Mile Lake.

Hence, our observations indicate that the present margins of the Kingston terrane on both the northwest and the southeast are late brittle faults.

PREVIOUS WORK IN THE KINGSTON TERRANE

A review of previous geological interpretations of the Kingston terrane is necessary in order to provide an historical perspective and demonstrate how the view of the geology has evolved. Bailey (1865) introduced the name Kingston Group to denote volcanic rocks of the Kingston Peninsula and considered them to be Silurian in age on the basis of lithological similarities to volcanic rocks interbedded with fossiliferous strata in other parts of the region. Subsequently, Bailey and Matthew (1872) expressed doubts about this correlation and suggested that a comparison to the Precambrian Coldbrook Group of the Saint John area was more likely, a position they maintained in their later reports (see Ells (1887) for a historical review on the difficulties encountered in distinguishing Precambrian from Silurian volcanic rocks in southern New Brunswick). Hayes and Howell (1937) gave formational status to the rocks on the Kingston Peninsula, and referred to them as the Kingston volcanics. Alcock (1938) recommended that the name Kingston Group be abandoned, and that all the presumed Precambrian volcanic rocks in southern New Brunswick be assigned to the Coldbrook Group. However, on his map of the Maritime Provinces, Alcock (1949) placed the Kingston volcanic rocks in the Silurian with the proviso that they may be in part pre-Silurian in age.

Both Grant (1971) and O'Brien (1976) mapped in the Kingston Peninsula and assigned the volcanic rocks to the Coldbrook Group. Grant (1971) divided the Coldbrook Group into three units, two volcanic

and one intrusive, with boundaries described as gradational. He described the lower unit to consist mostly of grey tuff and flows of uncertain composition and pink to grey flows, volcanic breccia, and crystal tuff of dacitic composition. Also present locally are ash beds with younging direction indicated by cross-bedding and graded bedding showing that the sequence is right way up. The upper volcanic unit of Grant (1971) is characterized by abundant tuff, volcanic breccia, and flows of quartz latite to dacite composition, with minor andesite. The youngest unit was described as granodiorite, in places gradational to fine-grained flows. It corresponds to the granite-like unit of Cumming (1916), and occurs in the central part of the peninsula. Grant (1971) also noted the presence of abundant mafic sheets that he described as dioritic in composition. O'Brien (1976) put most of the Coldbrook Group in a single unit of rhyolite and felsic pyroclastic rocks with interbedded flows and tuffs invaded by stratiform "basic" (mafic) sills. He also noted rhyolite porphyry sheets that he interpreted to be extrusive because of the absence of chilled margins and two granitic bodies that he named the Sand Point and Centreton plutons, corresponding approximately to the granodiorite unit of Grant (1971). Based on the presence of abundant brecciated intrusive rhyolite and tuffisite, he inferred that the intrusions are subvolcanic.

The Kingston terrane was included in the regional mapping project of Ruitenberg *et al.* (1979), who termed the volcanic rocks the "Western volcanic belt" of the Coldbrook Group. They divided most of the belt into felsic flows (their unit 6a) and felsic tuff (their unit 6b). However, in the vicinity of the Saint John River and Highway 7, they separated out a "Westfield intrusion", described as pink to grey, very fine-grained porphyritic felsic sills and dykes with associated diabase, that corresponds approximately to the Sand Point Pluton (Figure 2).

Rast (1979) focussed on the mafic sheets in the Kingston belt, which he termed meta-diabase dykes. He showed them to occur more or less in the core of the belt, and noted that they were intruded into principally felsic volcanic rocks of what he termed the Coldbrook Supergroup. He described the dykes as being separated by septa of granitic, granophyric, rhyolitic and pyroclastic rocks, all in the upper greenschist facies, and related the dykes to the opening of the Iapetus Ocean in the late Precambrian. Subsequently, Rast and Dickson (1982) described the Pocologan mylonite zone, and concluded that at least the southeastern part of the "dyke complex" is mylonitic but that the effects of deformation die out to the northwest.

Currie (1984) divided the Coldbrook Group of the Kingston Peninsula into two parts, the Kingston complex (a mafic and felsic dyke swarm) and volcanogenic rocks including flows, for which he retained the name Coldbrook Group. He suggested that the volcanic rocks do not occur southwest of the Saint John River and, in subsequent papers (Currie 1986, 1987), he showed the Kingston complex in that area to be bounded by mainly Late Precambrian granitoid plutons. In contrast, Dickson (1985) showed the Kingston belt, from the Loch Alva area through to Beaver Harbour, to consist of the Coldbrook Group, and described the rocks as crystal-lithic lapilli tuff, crystal tuff, and porphyritic rhyolite flows.

McCutcheon and Ruitenberg (1987) interpreted most of the Kingston Peninsula and the areas southwest of the Saint John River to the Loch Alva area to be part of the Coldbrook Group. They divided the group into a mainly felsic volcanic unit that dominates the southern part of the Kingston peninsula, and a mainly mafic volcanic unit that dominates the northern part. They noted that sedimentary rocks are rare and mainly on the northern side. However, they also recognized a unit through the central part of the map area that they called the Kingston Dyke Swarm, assumed to be Late Precambrian in age, that includes mafic and felsic dykes, mylonitic rocks, and minor volcanic rocks; these rocks were excluded from the Coldbrook Group. McCutcheon and Ruitenberg (1987) showed the Centreton Pluton of O'Brien (1976)

as an unnamed body of pink to grey fine- to medium-grained granitic rocks. Dostal and McCutcheon (1990) presented chemical data from the Western volcanic belt of Ruitenberg *et al.* (1979). However, most of their samples are from rocks now included in the Silurian Long Reach Formation or Neoproterozoic Belleisle Bay Group (Figure 2), not from the Kingston Group as here defined.

Doig *et al.* (1990) provided definitive evidence that rocks in the Kingston belt are not Precambrian. They reported U–Pb (zircon) ages of ca. 440 Ma for two units on Highway 7 that they interpreted to be felsic dykes. These rocks are part of the Westfield intrusion of Ruitenberg *et al.* (1979), or Sand Point Pluton of O'Brien (1976) and Barr *et al.* (1997, 1999).

Eby and Currie (1993) interpreted the Kingston terrane to be composed mainly of bimodal (mafic–felsic) sheeted dykes of the Kingston dyke complex. They claimed that the complex consists of sub-equal proportions of mafic and salic (felsic) dykes, but noted the presence of screens up to 20 m wide that consist almost entirely of intermediate to felsic volcanic rocks that resemble the Coldbrook Group. They also noted that none are known southwest of Highway 7, but showed these rocks flanking the dyke complex in the Kingston Peninsula. Because of the work of Doig *et al.* (1990), Eby and Currie (1993) recognized that the dykes are Silurian, but still considered the flanking volcanic rocks to be Late Proterozoic (Coldbrook Group and related rocks).

McLeod *et al.* (1994) divided volcanic and sedimentary rocks of the Kingston Peninsula into the Silurian Williams Lake and Bayswater volcanics, separated by the Kingston Dyke Complex and two granitic plutons both named Centreton. The southwestern part of the terrane was mainly assigned to the Kingston Dyke Complex, with a narrow belt of Coldbrook Group along the southeastern margin in the Pocologan area. Silurian U–Pb (zircon) ages were obtained from the Centreton pluton and a tuffaceous unit in the Bayswater Group (M. McLeod, unpublished data, cited in Barr *et al.* 1997). Schreckengost and Nance (1996) interpreted the terrane to be dominantly a mafic–felsic dyke complex emplaced in a Silurian–Devonian dextral shear zone.

OVERVIEW OF RESULTS OF THE PRESENT STUDY

As outlined above, by the mid-1990s, it was recognized that both volcanic and plutonic rocks of Silurian age are present in the Kingston terrane, but the full extent of these rocks was yet to be demonstrated. Hence, a mapping programme was initiated in the Kingston terrane in 1996 with the main purpose to determine the extent of Silurian volcanic and plutonic rocks. A preliminary map of the Kingston Peninsula was released two years later (Barr and White 1998), and maps of the entire terrane, as well as the adjacent Brookville terrane, at a scale of 1:20 000 have been published recently (Barr and White 2001). This work confirmed that the Kingston terrane contains a high proportion of metavolcanic (mainly tuffaceous) rocks of Silurian age (Figure 1). Although Barr *et al.* (1997, 1999) and Barr and White (1998) used the name Bayswater Group for the metavolcanic–metasedimentary rocks, following McLeod *et al.* (1994), Barr and White (2001) reverted to Kingston Group because of its historical precedence (Bailey 1865).

High-level granitic plutons are a major component of the Kingston terrane, and the largest (previously unrecognized) pluton, West Branch Reservoir, forms most of the southwestern part (Figure 3). The plutons consist mostly of fine-grained aphyric to porphyritic granite, and include abundant screens of volcaniclastic rocks. In many outcrops, granite is difficult to distinguish from felsic volcanic rocks. Hence, the field observations in this project were aided by the study of five hundred rock slabs stained for K-feldspar (Hutchison 1974), which enhances the texture of the samples, as well as by the examination of

most samples in thin section. Mafic sheets, typically 2 to 6 m wide, occur in all units but are especially abundant in the plutons. They have chilled margins against the host volcanic and granitic units, and are clearly younger. The mafic sheets are metamorphic rocks that consist mainly of plagioclase and amphibole, and are properly termed amphibolite.

Regional deformation and upper greenschist facies metamorphism produced a moderate to strong northeast-trending, steeply dipping phyllitic to locally schistose or slaty foliation in most rocks of the Kingston terrane (Barr *et al.* 1999). The foliation is typically subparallel to primary layering in rocks of the Kingston Group and to mafic sheet orientations. This observation suggests that both bedding and mafic sheets may have been transposed into the foliation plane, resulting in the sill-like appearance of the sheets. A steep intersection lineation is widely developed, especially in the southwestern part of the terrane, but the mylonitic fabric noted by earlier workers appears to be mainly confined to adjacent units.

Chemical data indicate that the volcanic and granitic rocks are comagmatic, and formed in a volcanic-arc setting, whereas the amphibolite sheets are tholeiitic and formed in an extensional regime (Barr *et al.* 1999). New U–Pb (zircon) ages (Miller *et al.* 2000) have confirmed earlier indications (Doig *et al.* 1990; M. McLeod, personal communication 1997) that the volcanic and granitic rocks are Silurian (ca. 435 Ma). The age of the dykes and timing of regional metamorphism are constrained by $^{40}Ar/^{39}Ar$ ages of ca. 420 to 390 Ma (but mainly ca. 410 Ma) for hornblende in mafic sheets from the Kingston Peninsula through to the Beaver Harbour area (Nance and Dallmeyer 1993).

FORMATIONS OF THE KINGSTON GROUP

Introduction

The Kingston Group is divided into five formations on the basis of lithological variations (Barr and White 2001). Although the rocks have been metamorphosed to upper greenschist facies and are typically foliated, primary igneous or sedimentary features are generally recognizable, and hence the rocks are named according to the inferred protolith characteristics based on their mineralogy and textural features. They are generally best exposed in the Kingston Peninsula, where the terrane is wider and less dominated by granitoid plutonic rocks than in the southwest (Figure 1). The formations form linear belts that trend slightly obliquely to the faults that bound the terrane (Figures 2 and 3). Although younging direction criteria are sparsely preserved, scattered occurrences of graded bedding and cross-bedding in minor epiclastic units indicate that the sequence youngs consistently to the northwest, with no repetition of formations, contrary to the synclinal interpretation of Grant (1971). Although most rock types occur in more than one formation, each formation as a package is distinctive. Contacts between units appear to be gradational. It should be noted that the representative sections mentioned below have not been mapped in detail. Also, volcanic sequences typically show rapid lateral variation and internal heterogeneity, and hence type sections cannot be as rigorously defined as in sedimentary sequences. Amphibolite sheets are not included in the descriptions below, but are present in most outcrops.

Raymond Mountain Formation

The Raymond Mountain Formation takes its name from Raymond Mountain, a prominent hill (elevation 170 m) on the southeastern margin of the Kingston Peninsula. Rocks assigned to the formation are well exposed in brooks and roadcuts in the vicinity of the mountain, in particular in brooks near Peekaboo

Corner, and in road cuts on the steep southern margin of the Kingston terrane near Central Norton (Figure 1). The proposed type section (thickness about 500 m) is exposed in roadcuts along Highway 121 (Ravine Road) and in adjacent Ravine Brook. The formation is in faulted contact (Kennebecasis fault) with Carboniferous rocks on the southeast, and hence the bottom of the formation is not exposed. The maximum exposed thickness is approximately 1000 m.

The Raymond Mountain Formation consists mostly of dark grey basaltic to andesitic lithic and lithic-crystal lapilli tuff. Dominant minerals in the groundmass are sodic plagioclase, chlorite, epidote, and biotite. Crystals are mainly of sodic plagioclase, and lithic clasts are mainly andesitic, with flow-aligned plagioclase laths. Dacitic lithic lapilli tuff with felsic clasts is a minor component of the formation in the upper part of the type section, indicative of the gradational relationship with the overlying Bayswater Formation.

Bayswater Formation

The Bayswater Formation is a major unit that can be traced from the Peekaboo Corner area southwest across the Saint John River to the West Branch Reservoir area (Figure 1). It is well exposed along the northwestern shore of Kennebecasis Bay, in road cuts in the Bayswater area, and on both shores of the Saint John River. Exposures in road cuts along Highway 7 where it crosses the formation can be considered a type section because of ease of access, although the section there is thinner and less well exposed than in the Kingston Peninsula, where the estimated maximum thickness of the formation is 4000 m.

Rocks in the Bayswater Formation are mainly grey, rhyolitic to dacitic, lithic to lithic-crystal lapilli tuff (Figure 4a, 4b). Welded and flow-banded textures are commonly preserved. Lithic clasts comprise 50 to 90% of most samples, vary in colour from dark grey to pink or white, and include both tuff and flow fragments. Most rocks also contain abundant small crystals of feldspar and aggregates of polygonal quartz. The groundmass is a fine-grained mixture of microcrystalline quartz and feldspar, with variable amounts of muscovite, chlorite, epidote, and biotite. Dark grey andesitic lithic tuff, thin-bedded tuffaceous siltstone, and micaceous phyllite are minor components of the unit.

Waltons Lake Formation

The Waltons Lake Formation can be traced through the Kingston Peninsula and across the Saint John River to Highway 7, but appears to be cut off on the southwest by the Sand Point Pluton (Figure 1). It has a maximum thickness of about 2500 m in the northern part of the Kingston Peninsula, but thins to only 400 m in the section on Highway 7. Although the rocks in the Highway 7 section are readily accessible, a better indication of the rock types in the unit can be seen on trails and logging roads northeast of Waltons Lake, which can be regarded as the type area.

The formation consists dominantly of rhyolitic crystal lapilli tuff, laminated ash tuff, and possibly felsic flows. Lithic tuff and lithic clasts are much less abundant than in the Bayswater Formation. Crystals are mainly of plagioclase, with minor clusters of polygonal quartz, and rare K-feldspar. The groundmass is generally composed of cryptocrystalline quartz and feldspar; foliated samples also contain muscovite, chlorite, and biotite. Evidence of relict ignimbritic flow banding, marked by alternating cryptocrystalline and fine-grained layers, is common. Locally, some layers contain relict spherulites. Rare phyllitic and garnet-bearing metasiltstone layers are similar to those in the Bayswater Formation.

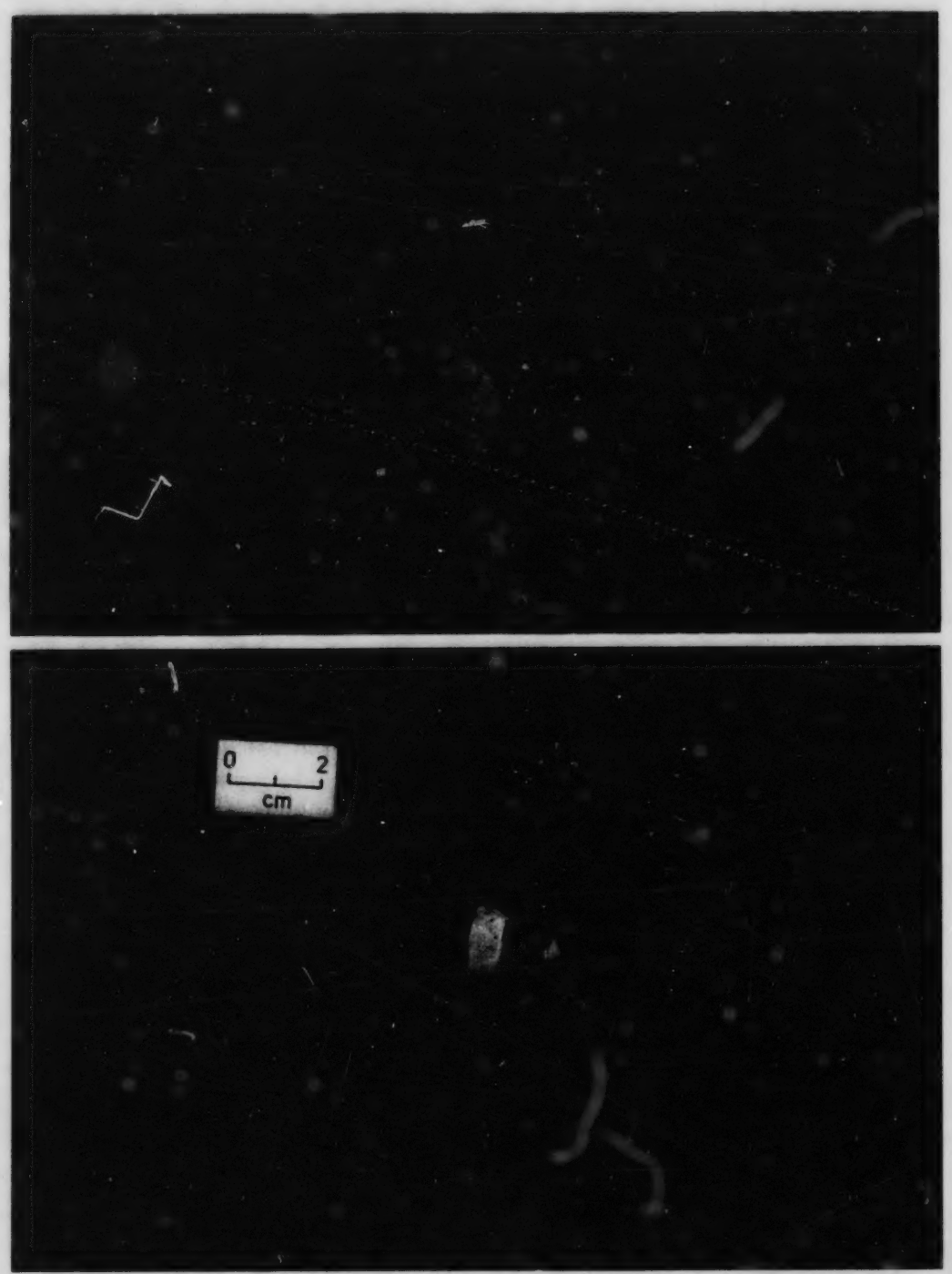

Figure 4. (a) Outcrop photograph of typical dacitic lithic lapilli tuff of the Bayswater Formation, with white to pink rhyolitic clasts. Hammer handle is 25 cm long. (b) Slabbed hand specimens of typical dacitic lithic (left), lithic-crystal (bottom right), and crystal (top right) lapilli tuff of the Bayswater Formation. The crystal tuff on the upper right is from the locality near Bayswater dated at ca. 438 Ma (M. McLeod, personal communication, 1996).

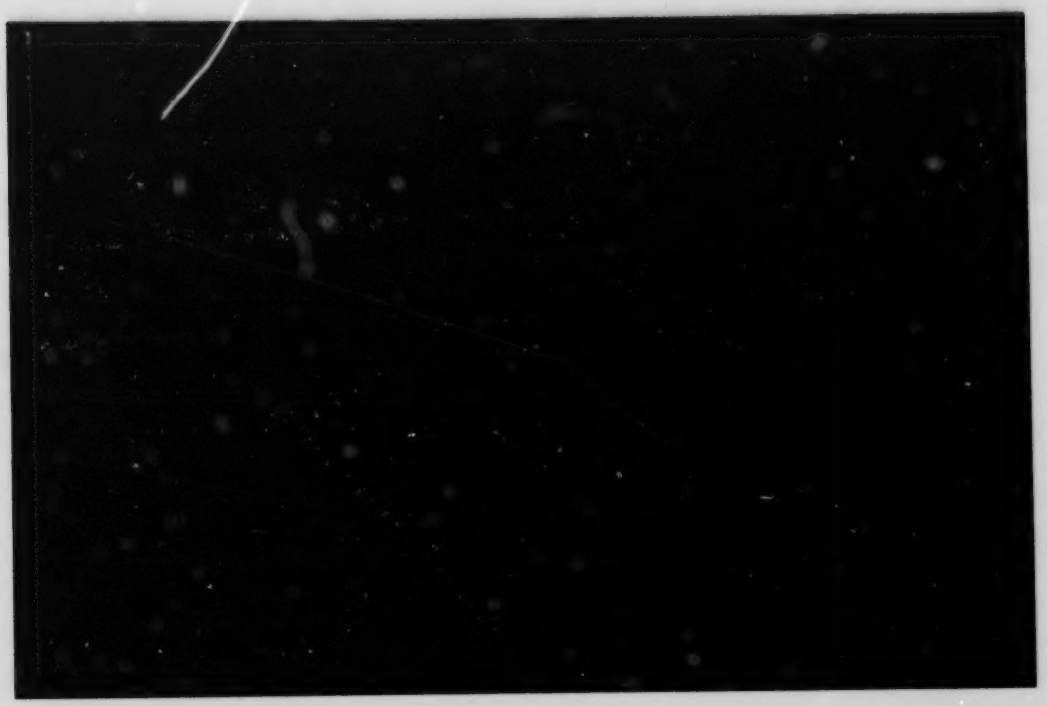

Figure 5. Outcrop of typical dacitic lithic lapilli tuff of the Westfield Formation. Hammer handle is 25 cm long.

Westfield Formation

The Westfield Formation is well exposed along the shore of Loch Alva, and in road cuts along Highway 7, 2–3 km southwest of the village of Westfield, which can be considered the type section (Figure 1). Thickness may be as much as 3500 m in the area between Highway 7 and Loch Alva. The formation consists dominantly of grey dacitic to rhyolitic lithic-crystal and crystal lapilli tuff. In contrast to lithic clasts in the Bayswater Formation, the clasts generally consist of pink and white dacitic to rhyolitic ash tuff and flow fragments that commonly display aligned microlites of plagioclase and, locally, preserve spherulitic textures. Thin agglomerate layers with white-weathered rhyolitic clasts up to 30 cm in diameter occur locally (Figure 5). Crystals in the tuff are plagioclase, K-feldspar, and quartz. Grey andesitic lapilli tuff layers of variable thickness are a minor component, and differ from andesitic tuff in the Bayswater Formation in having small (<0.5 mm), euhedral relict phenocrysts of amphibole. The Westfield Formation includes tuffaceous siltstone horizons similar to those in the Bayswater Group, and interbedded brown phyllitic to schistose pelitic rocks. Rare garnet forms tiny euhedral grains associated with biotite-rich layers. Toward the northeast beyond Erbs Cove, the unit is poorly exposed but appears to be generally more rhyolitic. Outcrops in that area consist of fine-grained rhyolitic crystal tuff or rhyolitic flows with abundant feldspar crystals.

To the southwest (Figure 3), the Westfield Formation is interpreted to occur as screens within and adjacent to the West Branch Reservoir Granite along the length of the Kingston terrane. It is exposed in a road cut on Highway 1 near Pocologan, and a sample of dacitic to rhyolitic crystal tuff from that locality yielded a U–Pb (zircon) age of ca. 441 Ma (Miller *et al.* 2000), corroborating the Silurian age of the Kingston Group. Volcanic units on Campobello Island are also similar to the Westfield Formation.

Williams Lake Formation

The Williams Lake Formation is well exposed along Highway 860 on the northern side of the Kingston Peninsula southwest of Williams Lake, in roadcuts on Highway 7, and along the southeastern shore of Seven Mile Lake and adjacent logging roads. The section along the south shore of Seven Mile Lake is regarded as the type section. Maximum preserved thickness is about 1500 m, but the formation is terminated by the Belleisle fault, and the top is not exposed.

The formation is characterized by dark grey basaltic to andesitic flows, lithic to lithic crystal lapilli tuff, laminated tuffaceous siltstone, wacke, and black slate. Flows consist of flow-aligned microphenocrysts of plagioclase in a pilotaxitic groundmass of plagioclase microlites and fine-grained actinolite and chlorite. Small flattened amygdules are filled with epidote, chlorite, or albite. Mafic tuffs contain mainly clasts of porphyritic basalt and andesite. The formation also includes dacitic crystal-lithic lapilli tuff and flows, characterized by abundant small crystals of white, euhedral albitized plagioclase and rare quartz. Epiclastic rocks (siltstone, wacke, and black slate) contain abundant biotite and muscovite, and are interlayered with tuff. Around the southern shore of Seven Mile Lake, primary sedimentary structures, including soft-sediment deformation, graded bedding, and cross-bedding, are well preserved in epiclastic rocks.

A small atypical area of pale grey dacitic to rhyolitic flows and crystal-lithic lapilli tuff, locally ignimbritic and flow-banded, occurs in the formation northeast of Williams Lake.

CONCLUSIONS

The Kingston terrane consists mainly of Silurian metavolcanic and minor metasedimentary rocks and associated comagmatic high-level granitic plutons. Although metamorphosed and deformed, the metavolcanic and metasedimentary rocks preserve enough primary igneous and sedimentary features to enable them to be divided into six formations that young from southeast to northwest across the terrane. Amphibolitic sheets are younger than both the metavolcanic and granitic rocks and, hence, the terrane should not be viewed as a bimodal dyke complex. Brittle faults separate the Kingston terrane from Precambrian and younger rocks of the now-adjacent Brookville and New River terranes, and the original location of the Kingston terrane relative to these older terranes is not known. Additional studies are in progress to further assess the tectonic setting, regional implications, and economic potential of the Kingston Group and associated rocks.

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CAMBRIAN GRANITOID PLUTONS OF THE POCOLOGAN AREA AND THE CONTINUATION OF THE BROOKVILLE TERRANE TO THE WOLVES ISLANDS †

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Granitoid rocks in the Pocologan area of southern New Brunswick are divided into separate plutons based on mineralogy and texture. Most of the plutons are of granodioritic or granitic composition, but variably altered and deformed. In the most deformed area, termed the Pocologan Harbour granitoid belt, the granitoid protolith is typically unrecognizable and the rocks are mylonitic, with abundant fine- to medium-grained muscovite, biotite, epidote, ribbon quartz, and saussuritized plagioclase. A sample from the largest plutonic unit, the McCarthy Point Granodiorite, yielded a Cambrian U–Pb (zircon) age of 528 +4/-3 Ma, similar to ages previously reported from plutons elsewhere in the Brookville terrane. Although not yet dated, granitoid rocks on the Wolves Islands in the Bay of Fundy are also inferred to be part of the Brookville terrane, based on their mineralogical and textural similarity to granitoid rocks characteristic of the terrane.

On subdivise les roches granitiques du secteur de Pocologan dans le Sud du Nouveau-Brunswick en plutons distincts en fonction de leur caractéristiques minéralogiques et de leur texture. La majorité des plutons ont une composition granodioritique ou granitique, mais ils sont altérés et déformés de façon variable. Dans le secteur le plus déformé, appelé *ceinture granitique de Pocologan Harbour*, le protolithe granitique est généralement impossible à reconnaître et les roches présentes sont des roches mylonitiques comportant une quantité abondante de muscovite de grain fin à moyen, de biotite, d'épidote, de quartz rubané et de plagioclase saussuritisé. Une datation au U–Pb à partir de zircon a situé au Cambrien un échantillon provenant de l'unité plutonique la plus volumineuse, la granodiorite de McCarthy Point, lui attribuant un âge de 528 +4/-3 Ma, c.-à-d. un âge analogue aux âges antérieurement conférés à d'autres plutons du terrane de Brookville. Même si on n'a pas encore daté les roches granitiques des îles Wolves dans la baie de Fundy, on suppose qu'elles font partie du terrane de Brookville d'après leur similarité minéralogique et texturale avec les roches granitiques caractéristiques du terrane.

INTRODUCTION

The Brookville terrane of southern New Brunswick (Figure 1) includes abundant plutons that range in composition from gabbro to granite (e.g., White 1996; White and Barr 1996; Eby and Currie 1996). Barr and White (1989), White (1996), and White and Barr (1996) defined the Brookville terrane but did not

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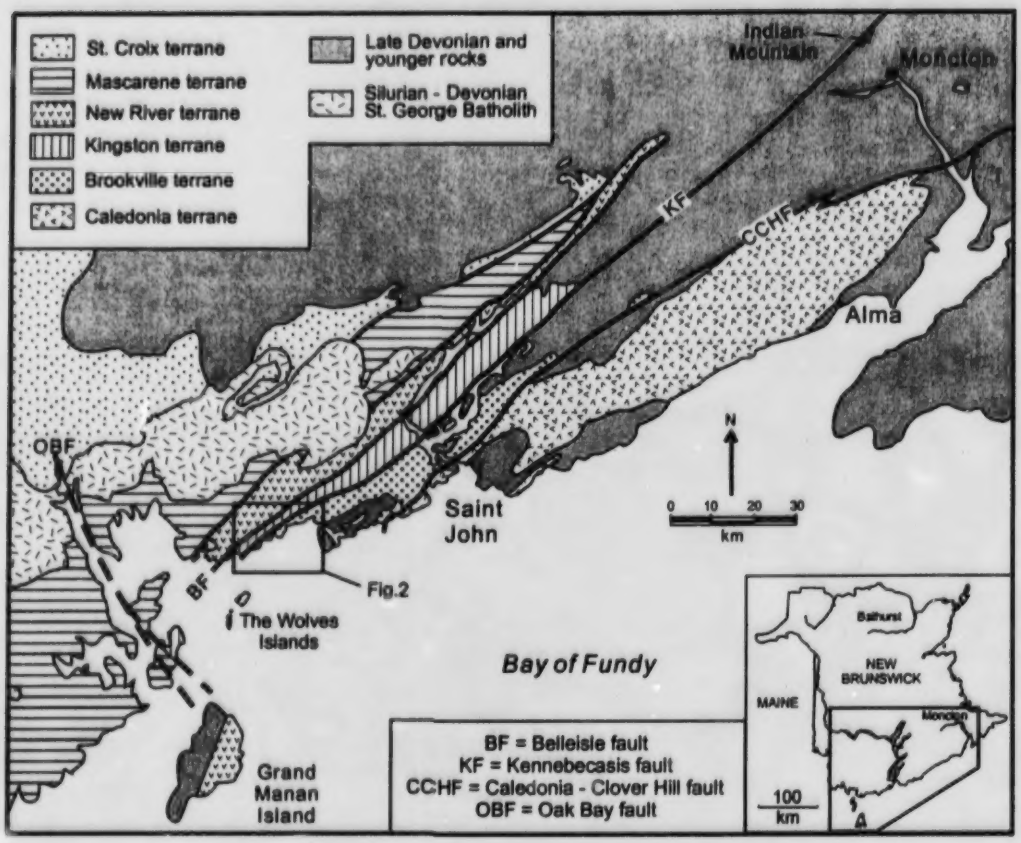

Figure 1. Terranes in southern New Brunswick, showing the location of the Brookville terrane between the Kennebecasis and Caledonia–Clover Hill faults (after White and Barr 1996).

trace it beyond the Lepreau area where plutonic rocks become more deformed, apparently in association with the Pocologan mylonite zone (Rast and Dickson 1982; Park *et al.* 1994).

The purpose of this paper is to name and describe the distribution and petrographic features of plutons in the Pocologan area (Figure 2), and to present a new U–Pb zircon age from one of the major plutons. The petrographic features and age confirm that these plutons are part of the Brookville terrane and, hence, should be included in the redefined Golden Grove Plutonic Suite of Barr and White (2001). In addition, we report field and petrographic observations for granitoid rocks on the Wolves Islands, located in the Bay of Fundy ca. 18 km southwest of Red Head (Figure 1), which indicate that they are also part of the Brookville terrane.

GEOLOGICAL SETTING

Southern New Brunswick is characterized by long narrow belts of rocks of contrasting composition and age, separated by major faults. The Brookville terrane is located between the Caledonia–Clover Hill fault on the southeast and the Kennebecasis fault on the northwest (Figure 1). It consists of the Green Head Group, Brookville Gneiss, Dipper Harbour volcanic unit, and abundant plutons (White 1996; White and

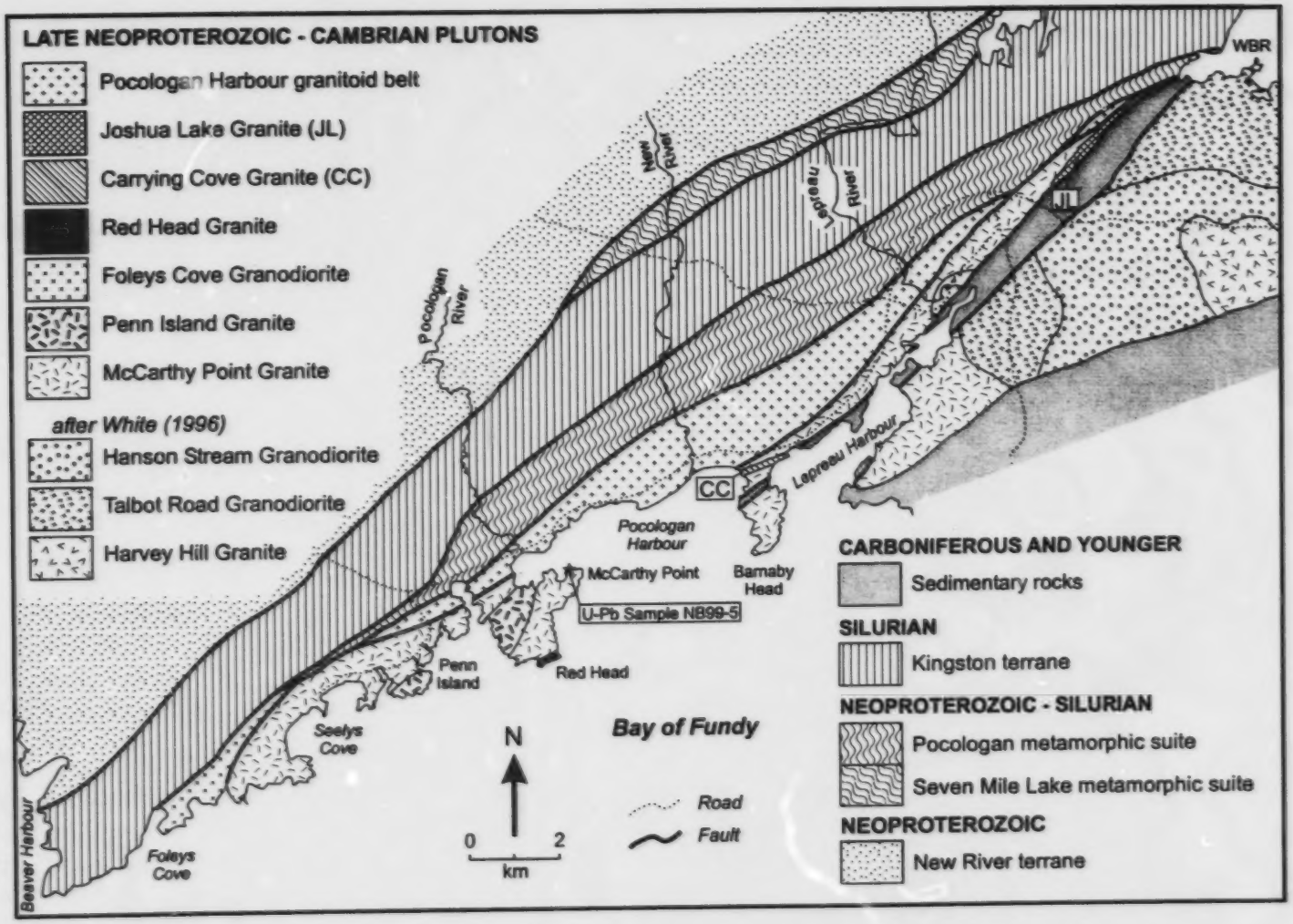

Figure 2. Geological map of the Pocologan area (after Barr and White 2001). **WBR** is West Branch Reservoir.

Barr 1996). The Green Head Group includes the Ashburn Formation (dominantly marble with minor metaclastic rocks) and the Martinon Formation (dominantly metasiltstone with minor calc-silicate rocks, quartzite, conglomerate, and marble); the two units are interpreted to be lateral facies equivalents (White and Barr 1996). Based on locally preserved stromatolites, Hofmann (1974) suggested that the Green Head Group is Neohelikian (Mesoproterozoic) in age, but more recent assessment suggested a minimum age of ca. 750 Ma (H. Hofmann, written communication, 1991). The Green Head Group is in tectonic contact with the Brookville Gneiss, a locally migmatitic paragneiss with sheets of granodioritic to tonalitic orthogneiss, minor calc-silicate and marble layers, and rare quartzite and amphibolite. The paragneiss, which comprises about 75% of the Brookville Gneiss, contains detrital zircon indicating a maximum depositional age of ca. 640 Ma (Bevier *et al.* 1990). The orthogneiss has an igneous crystallization age of 605 ± 3 Ma, and was metamorphosed to amphibolite facies at 564 ± 6 Ma (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). These dates indicate that, contrary to earlier interpretations (e.g., Nance 1987), the Brookville Gneiss is younger than the Green Head Group and, hence, does not represent its basement. However, the original relationship between the two units remains problematic.

The Green Head Group and Brookville Gneiss have been intruded by plutons that range in composition from gabbroic to granitic, and have yielded U–Pb dates of ca. 555 Ma to 537 Ma (White 1996; Currie and Hunt 1991; Currie and McNicoll 1999). Their petrological characteristics suggest that they constitute a typical calc-alkalic I-type granitoid suite, probably emplaced in a continental margin subduction zone (White 1996; Eby and Currie 1996). The ca. 550 Ma Dipper Harbour volcanic unit (Zain Eldeen 1991) may represent part of the contemporaneous volcanic-arc complex. Although Eby and Currie (1996) and Currie and McNicoll (1999) suggested that the plutons of the Brookville terrane are related to those in the adjacent Caledonia terrane and the New River terrane to the north, Barr and White (1996) argued that they are younger and part of a separate and unrelated tectonic regime.

PLUTONS IN THE POCOLOGAN AREA

Introduction

Ruitenberg *et al.* (1979) applied the name Red Head Pluton to granitoid rocks of the Pocologan area and included them in their "Western intrusive belt," a region that coincides approximately with the Brookville terrane of Figure 1. They described the Red Head Pluton as granodiorite and quartz diorite with lesser granite and diorite, and assigned an Ordovician or earlier age. They also described in some detail the variable degree of deformation in the rocks, ranging from weak cataclasis (no planar fabric developed), to more intense cataclasis and extreme cataclasis with a well-developed planar fabric.

Dickson (1985) described most of the granitoid rocks of the Pocologan area as Hadrynian foliated granodiorite, granite, and gabbro. Currie (1988) included plutons in the Pocologan area, as well as plutons to the north of the Kingston terrane in the present New River terrane (Figure 1), in the Golden Grove Suite. He recognized separate plutons, including the Red Head pluton and undivided granodiorite and granite. McLeod *et al.* (1994) assigned all the granitoid rocks in the Pocologan area to the Red Head granitoids of Hadrynian age. White (1996), White and Barr (1996), and Eby and Currie (1996) did not include the Pocologan area in their descriptions of plutons in the Brookville terrane.

In the present study, granitoid rocks in the Pocologan area have been divided into separate plutons based on field observations and petrographic features (Figure 1). Because difficult access and steep cliffs in parts of the coastal section limited the extent of detailed mapping and sampling, the division is only

approximate. Also, it was not generally possible to determine the nature of original contacts between plutons because of the present degree of deformation; most of the contacts now appear to be faults. Hence the relative ages of the plutons are not generally known. Islands in Pocologan Harbour have not yet been mapped. Within the above limitations, we have divided the granitoid rocks in the Pocologan area into seven units, as shown on Figure 2 and described below. The units are described in approximate order of geographic location from southeast to northwest because of some uncertainty in relative ages.

The study area overlaps with the southwestern part of the Brookville terrane as described by White (1996). The Harvey Hill Granite, Hanson Stream Granite, and Talbot Road Granodiorite (Figure 2) are as defined by White (1996), but the Lepreau and Lepreau Harbour plutons of White (1996) have been renamed, as explained below.

McCarthy Point Granodiorite

The McCarthy Point Granodiorite is well exposed in the area of McCarthy Point, and also in roadside and shoreline outcrops in the area of Seelys Cove. It also extends east and north of Lepreau Harbour, and thus includes the Lepreau Harbour pluton and part of the Lepreau pluton of White (1996). The composition varies from granodiorite to tonalite. Characteristically, mafic minerals include both biotite and hornblende and form 10–15% of the rock. The biotite is generally altered to chlorite. Texture is medium-grained hypidiomorphic granular, with subhedral saussuritized plagioclase grains and interstitial quartz and K-feldspar. The rocks are less altered in the part of the pluton east of Lepreau Harbour (Lepreau Harbour pluton of White 1996). Although similar in texture and mineralogy to the Talbot Road Granodiorite of White (1996), the McCarthy Point Granodiorite contains a lower proportion of mafic minerals, particularly hornblende.

Granitoid rocks on Barnaby Head are also included in the McCarthy Point Granodiorite (Figure 2), although in places they are very deformed and resemble components of the Pocologan Harbour granitoid belt described below. These deformed rocks in places resemble crystal tuff, which may explain the presence of volcanic unit shown on some previous maps of Barnaby Head (e.g., McLeod *et al.* 1994). At the tip of Barnaby Head, a dyke of what appears to be Penn Island Granite occurs in the McCarthy Point Granodiorite, suggesting that the Penn Island Granite is younger.

Penn Island Granite

The Penn Island Granite outcrops on Penn Island and adjacent headlands, and also on the McCarthy Point peninsula. It is medium to coarse grained, with relatively smaller subhedral plagioclase grains surrounded by large quartz and K-feldspar grains. It contains less than 10% altered mafic minerals that appear to have been entirely biotite, now replaced by chlorite and epidote. Plagioclase is intensely saussuritized, except for sodic rims. As noted above, a dyke of granite similar to the Penn Island Granite occurs in granodiorite at the tip of Barnaby Head.

Foleys Cove Granodiorite

The original nature of the Foleys Cove unit is difficult to know because it is very deformed everywhere examined. The rock is generally coarse grained, shows no evidence for the former presence of amphibole, and only minor (a few per cent) chloritized biotite. Quartz and K-feldspar are abundant, in a matrix of saussuritized plagioclase. The quartz is ribboned and polygonized. Mylonitic bands a few millimetres in

width are present in which the original minerals are unrecognizable. One sample contains some relict granophyric texture.

Red Head Granite

The pluton that forms Red Head is distinctly different from other plutons in the area, and is in faulted contact with the McCarthy Point Granodiorite. It consists of homogeneous coarse-grained alkali-feldspar granite that is distinctly red in colour. Minerals present are perthitic orthoclase, minor plagioclase, and abundant cataclased quartz with intense undulatory extinction. Minor (less than 2%) chlorite occurs in clusters of small flakes, apparently having replaced biotite.

Carrying Cove Granite

The Carrying Cove Granite occurs in a faulted sliver in the Carrying Cove area and also northeast of Lepreau River (Figure 2). Although also red, it differs from the Red Head Granite in having a higher biotite content (ca. 5%) and subhedral plagioclase grains. It differs from the Hanson Stream Granodiorite of White (1996), a sliver of which occurs to the northeast of the Carrying Cove Granite, in its red colour and lack of the large, almost porphyritic, quartz crystals and abundant dioritic xenoliths that characterize the Hanson Stream unit.

Joshua Lake Granodiorite

The Joshua Lake Granodiorite occurs in a thin sliver in the area of Joshua Lake. It is a distinctive medium-grained red granodiorite with abundant amphibole (ca. 20%). In hand specimen it appears similar to the Carrying Cove Granite, but the Carrying Cove Granite contains more K-feldspar and no amphibole. Based on one area of outcrop, the southwestern part of the Joshua Lake body appears to be coarser grained and more granitic.

Pocologan Harbour Granitoid Belt

The Pocologan Harbour granitoid belt occurs between the Pocologan metamorphic suite and the less deformed granitoid plutons described above. It consists of a mixture of highly deformed granitoid rocks that include the McCarthy Point Granodiorite and the Penn Island Granite, as well as more dioritic rocks. However, subdivision or recognition of protoliths is difficult due to the extent of deformation and recrystallization. The intensity of deformation varies gradationally from areas where granitoid texture is evident to places where the rocks appear fine grained and retain little evidence for a granitoid protolith. The latter areas may be those mapped as sedimentary by Park *et al.* (1994), but it appears that none of the rocks in the belt are sedimentary. Little of the original granitoid mineralogy is present in these rocks, which contain abundant fine- to medium-grained muscovite and epidote, minor biotite, and no amphibole. Quartz forms long ribbons. Plagioclase is highly saussuritized, and in less deformed samples forms augen. Little K-feldspar has survived.

The contact between the Pocologan Harbour granitoid belt and less deformed adjacent plutons appears to be a brittle fault, as the change is abrupt between units containing metamorphic mica and those that do not. The northwestern margin also appears to be a brittle fault, as components of the Pocologan Harbour granitoid belt are not present in the Pocologan metamorphic suite (Grace 2000). It appears that the Pocologan metamorphic suite has closer affinity with the Kingston terrane than the Brookville terrane

and, hence, this fault is likely to be related to the Kennebecasis fault that separates the Brookville and Kingston terranes farther to the northeast (Figure 1).

GRANITOID ROCKS ON THE WOLVES ISLANDS

Ritchie (1985) showed that East Wolf Island, the largest of the Wolves Islands (Figure 1), is underlain mainly by granitic rocks, intruded by scattered mafic dykes. This work was corroborated during the present study by a reconnaissance examination of outcrops around the shore of East Wolf Island, and also adjacent smaller islands. However, the rocks appear more heterogeneous than suggested by Ritchie (1985), and in addition to the dominant biotite–hornblende granodiorite to tonalite, also include quartz diorite and minor coarse-grained granite. In addition to biotite and hornblende, the more mafic rocks contain relict pyroxene in the cores of hornblende grains.

U–PB (ZIRCON) AGE

Prior to the present study, none of the plutons in the Pocologan area had been precisely dated, although granitoid plutons in the Brookville terrane to the northeast of the Pocologan area had yielded U–Pb (zircon) ages between 550 Ma and 537 Ma (White 1996; Currie and Hunt 1991; Currie and McNicoll 1999). In order to determine if the granitoid rocks of the Pocologan area are of similar age, a sample was collected for U–Pb dating from the McCarthy Point Granodiorite near McCarthy Point. This unit was selected for dating because of its large extent through the area and relative homogeneity. Dating was done at the Isotope Geochemistry Laboratory at the University of North Carolina at Chapel Hill. Zircon grains were separated from a ca. 25 kg sample, using standard techniques, sorted according to morphology and clarity under a binocular microscope, and abraded to remove the outermost portions of grains that are most likely to have been affected by Pb loss. Procedures and analytical techniques generally followed those described by Miller *et al.* (2001).

The McCarthy Point granodiorite sample contained zircon grains of several different morphologies. In general, smaller grains were clear and inclusion-free and larger grains tended to be slightly metamict. Seven zircon fractions were analysed in total, of which five consisted of only one or two grains in order to reduce the risk of analyzing inherited components, and the remaining two were multi-grain fractions to ensure that the single- and two-grain fractions were not biased. The full data set will be presented in a subsequent publication.

The seven fractions analyzed show no sign of inheritance (Figure 3). In general, the metamict zircons are more discordant than clear zircons, despite both types being highly abraded. All seven fractions form a discordant trend with an upper intercept of 528 +4/-3 Ma (MSWD = 1.6). We interpret this date as the time of crystallization of the McCarthy Point Granodiorite.

REGIONAL IMPLICATIONS

The petrologic features of granitoid rocks in the Pocologan area and on the Wolves Islands are typical of plutons in the Brookville terrane, justifying the extension of the terrane an additional 30 km beyond Lepreau Harbour into the Bay of Fundy (Figure 1). However, the position of the terrane beyond the Wolves Islands is uncertain, as similar plutons do not occur on Grand Manan Island (Fyffe and Grant 2000), or in coastal Maine (Hogan and Sinha 1989).

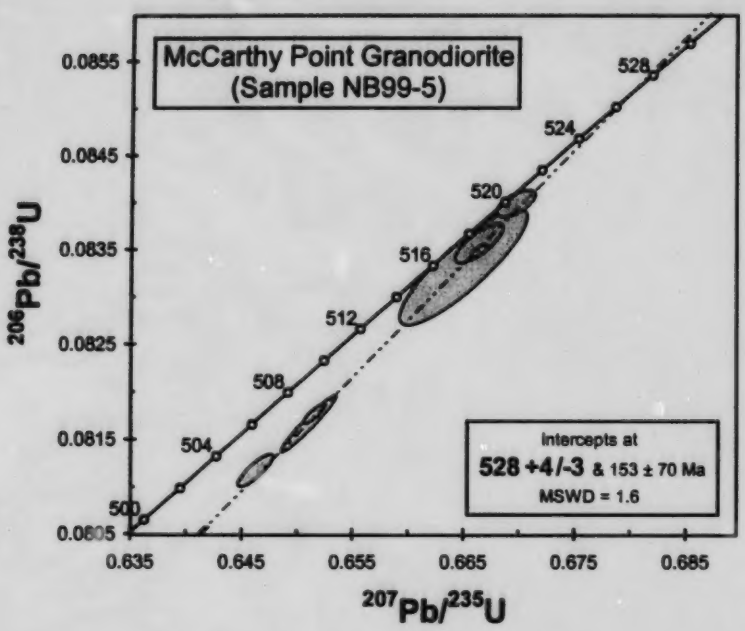

Figure 3. U–Pb concordia diagram for sample NB99-5 from the McCarthy Point Granodiorite (sample location shown on Figure 2).

The ca. 528 Ma age for the McCarthy Point granodiorite further supports the interpretation of White and Barr (1996) that plutons of the Brookville terrane are younger than those of the Caledonia or New River terranes (ca. 550–528 Ma compared to ca. 620 Ma and 558–548 Ma). Samson *et al.* (2000) showed that they are also isotopically distinct, with more evidence for crustal interaction in their evolution. The term "Golden Grove Intrusives" was used initially to include the Brookville Gneiss and associated plutonic rocks in the vicinity of the city of Saint John (Hayes and Howell 1937; Williams *et al.* 1985). The name Golden Grove Suite was subsequently used to include plutons over a wider area in southern New Brunswick (e.g., Ruitenberg *et al.* 1979; Currie 1988). Recognizing that it is useful to have a collective name for related plutons, we suggest that the term Golden Grove Plutonic Suite be used to refer to the latest Neoproterozoic to Cambrian gabbroic to granitic plutons of the Brookville terrane, including those in the Pocologan area described here. Thus defined, the Golden Grove Plutonic Suite excludes the Brookville Gneiss, which has been shown to be older (Bevier *et al.* 1990; Dallmeyer *et al.* 1990). It also excludes the mainly older plutons of the Caledonia and New River terranes.

Additional work is in progress to better determine relative ages of plutons in the Pocologan area, and to compare their chemical characteristics with those of plutons elsewhere in the Brookville terrane.

ACKNOWLEDGEMENTS

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EVALUATION OF TOTAL, PARTIAL AND SELECTIVE LEACH DATA FROM HUMUS, B-HORIZON AND TILL: A CASE STUDY FROM THE CLARENCE STREAM GOLD PROPERTY, SOUTHERN NEW BRUNSWICK †

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A gold occurrence originally discovered by a prospector following up National Geochemical Reconnaissance stream-sediment data was the focus of a detailed sampling program carried out in the McDougall Lake (NTS 21 G/07, 1:50 000) map area. Surficial materials were collected at sites along lines crossing known and inferred mineralization. Different sample media (humus, B-horizon, and till) were analysed by various methods, including two selective leaches, mobile metal ion and enzyme leach.

Analytical results indicate that concentrations of Au determined by instrumental neutron activation analysis and, to a lesser extent, As, Sb and Ag determined by aqua regia digestion and inductively coupled plasma-mass spectrometry, are the best guides to mineralization. While the concentrations of these elements in the <63 μm fraction of till provide the best anomaly contrast (anomalous to background ratio), the <63 μm fraction of B-horizon soils produces good results, and is easier to collect. Hydromorphic transport of mobile elements such as Mo, U and F, and less mobile elements such as As and Sb, may lead to the formation of false or displaced anomalies in poorly drained areas. For all media, an analytical procedure consisting of an aqua regia digestion followed by analysis by inductively coupled plasma-mass spectrometry appears to produce the most conclusive data. Examination of the heavy-mineral concentrate fraction of tills suggests the presence of unmapped local greisen zones that are not apparent using other methods of analysis.

Une venue aurifère découverte à l'origine par un prospecteur assurant un suivi vis-à-vis de données provenant de sédiments fluviatiles du Programme d'exploration géochimique préliminaire a constitué le point de mire d'un programme d'échantillonnage détaillé réalisé dans le secteur cartographique du lac McDougall (SNRC 21 G/07, à l'échelle de 1/50 000). Des matériaux de surface ont été recueillis à divers endroits le long des lignes traversant des minéralisations reconnues et présumées. Divers supports d'échantillonnage (humus, horizon B et till) ont été analysés au moyen de diverses méthodes, notamment deux analyses à lixiviation différentielle, une analyse des ions métalliques mobiles et une analyse par lixiviation enzymatique.

Les résultats des analyses révèlent que les concentrations d'Au déterminées à l'aide d'une analyse instrumentale par activation neutronique et, dans une moindre mesure, les concentrations d'As,

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† Geological Survey of Canada ordinary budget.

de Sb et d'Ag déterminées par digestion à l'eau régale et par spectrométrie de masse avec plasma induit par haute fréquence constituent les meilleurs guides d'une minéralisation. Même si les concentrations de ces éléments dans la fraction <63µm du till fournissent le meilleur écart d'anomalies (valeurs anomales comparativement au rapport de référence), la fraction <63 µm des sols de l'horizon B produit de bons résultats et elle est plus facile à prélever. Le transport hydromorphe des éléments mobiles comme le Mo, l'U et le F et des éléments moins mobiles comme l'As et le Sb peut entraîner la formation de fausses anomalies ou d'anomalies déplacées dans les secteurs mal drainés. La réalisation d'une analyse comportant une digestion à l'eau régale suivie d'une analyse par spectrométrie de masse avec plasma induit par haute fréquence semble produire les données les plus concluantes dans le cas de tous les supports. L'examen de la fraction de minéraux lourds concentrés des tills laisse supposer la présence de zones locales non cartographiées de greisens qui ne sont pas visibles au moyen d'autres méthodes d'analyse.

INTRODUCTION

A gold occurrence east of Rollingdam in southwest New Brunswick was the focus of a detailed geochemical study by the Geological Survey of Canada. The original discovery was made in 1998 by local prospector Reg Cox, who found mineralized boulders while following up an anomalous gold value in stream sediment reported in a National Geochemical Reconnaissance open file report (Friske et al. 1992). Regional staff of the New Brunswick Department of Natural Resources and Energy had identified the potential of the Clarence Stream area for gold in an earlier report (McLeod 1990).

Freewest Resources acquired the 1635 ha (4040 acre) Clarence Stream property in 1999 and began a program of surface exploration (geophysics, geochemistry, detailed mapping) that soon revealed significant gold mineralization. Further geochemical sampling, trenching and channel sampling identified the extent of mineralization at surface.

In September 2000, staff of the Geological Survey of Canada undertook a detailed geochemical study over the Freewest claim. In addition to stream-silt and bulk stream-sediment collection for regional geochemical characterization, a high-density overburden sample program was carried out over the occurrence. Different sample media (humus, B-horizon, till, rocks) were analysed by various methods, including two selective leaches, mobile metal ion and enzyme leach.

The study was carried out to establish a regional and property-scale geochemical exploration strategy over potential gold host rocks adjacent to the Saint George Batholith. An evaluation of analytical data, incorporating local bedrock and surficial geology information and observations of local drainage, soil type and vegetation was carried out to establish potential pathfinder elements to gold mineralization and to determine which combination of analytical procedure and sample medium provided the best anomaly contrast under local conditions.

BEDROCK AND ECONOMIC GEOLOGY

The following description is taken from McLeod (1990), McLeod *et al.* (1994), McLeod *et al.* (1998), and Fyffe (1997), unless otherwise noted. The study area straddles the contact between sedimentary and

minor volcanic rocks of the Kendall Mountain and Oak Bay and Waweig formations, and the Lower Devonian Magaguadavic Granite (Figure 1). The Magaguadavic Granite forms part of the South Oromocto Lake Intrusive Suite, one of five suites comprising the Saint George Batholith, a mainly post-orogenic composite batholith. This portion of the Magaguadavic Granite is generally a medium- to coarse-grained megacrystic biotite to biotite–hornblende granite that contains abundant aplite veins locally. In addition to the Magaguadavic Granite, three small intrusions are mapped within the study area. The Pleasant Ridge, Beech Hill and Sorrel Ridge granites form part of the Pomeroy Intrusive Suite, the youngest and most highly evolved of the five Saint George Batholith suites. These metaluminous to peraluminous granite plutons of the Pomeroy Intrusive Suite are part of a more extensive series extending from the Tower Hill Granite in the west to the Mount Pleasant Granites in the east (Taylor *et al.* 1985).

Supracrustal rocks of the area consist of sedimentary rocks of the Mascarene and Cookson groups. The Ordovician Cookson Group includes the Digdeguash, Kendall Mountain and Woodland formations. Clastic sedimentary rocks, including wackes, siltstones and shales, dominate the sequence. The Mascarene Group includes the Oak Bay and Waweig formations of Silurian age. The former forms the base of the Silurian section in the area, and consists of polymictic pebble conglomerate interbedded with lithic arenites and siltstones. Siltstones and sandstones, which are in part calcareous, and locally abundant mafic and felsic tuffaceous volcanic rocks dominate in the Waweig Formation.

In general, the economic potential of the area, which is discussed in the context of endogranitic and exogranitic deposits, is largely related to the granitoid intrusions (McLeod 1990). Endogranitic mineral occurrences of tin–tungsten–molybdenum are mostly associated with rocks of the Pomeroy Intrusive Suite, which have been actively explored because of their proximity and similarity to the intrusions at the Mount Pleasant tin–tungsten and molybdenum polymetallic deposit. In contrast, base-metal- and gold-bearing quartz vein systems are notably associated with the contact aureoles (exogranitic) of the older and less differentiated phases of the Saint George Batholith, such as the Magaguadavic Granite.

Initial results from the surface exploration program conducted by Freewest Resources Canada, Inc. led to the discovery of intermittently exposed gold mineralization over a 2 km strike length. They describe the mineralization as intrusion-related, occurring "in quartz veins, replacements and stockworks, within biotite–cordierite hornfels and in skarn. Mineralization is hosted in brittle to ductile, deformation zones of the Waweig Formation that parallel the contact with the St. George Batholith, within metasedimentary and gabbroic rocks" (Freewest Resources Canada, Inc. News Release, April 19, 2001). An initial drilling program in the winter of 2001 returned one drill hole grading 15.1 g/t Au over a length of 21.0 m.

SURFICIAL GEOLOGY

The Freewest property lies within the Magaguadavic Highlands subdivision of the St. Croix Highlands (Bostock 1970; Rampton *et al.* 1984). Surficial geology of the area is defined by the Late Wisconsinan (20–10 ka) episode of glaciation and the Holocene epoch (10 ka to present). Rampton *et al.* (1984) divide the Late Wisconsinan in New Brunswick into six phases. Only the first two advances, the Chignecto (18–15 ka) and the Bantalor (13.3–12.7 ka) extended far enough south to affect the field area. During the Bantalor phase, ice flowed from the northwest, originating from an ice centre in northern Maine. Deglaciation of the field area took place between 13.1 ka and 12.9 ka (Rampton *et al.* 1984). When the ice retreated, drumlins and numerous northwest–southeast-trending ribbed or ridged moraines remained.

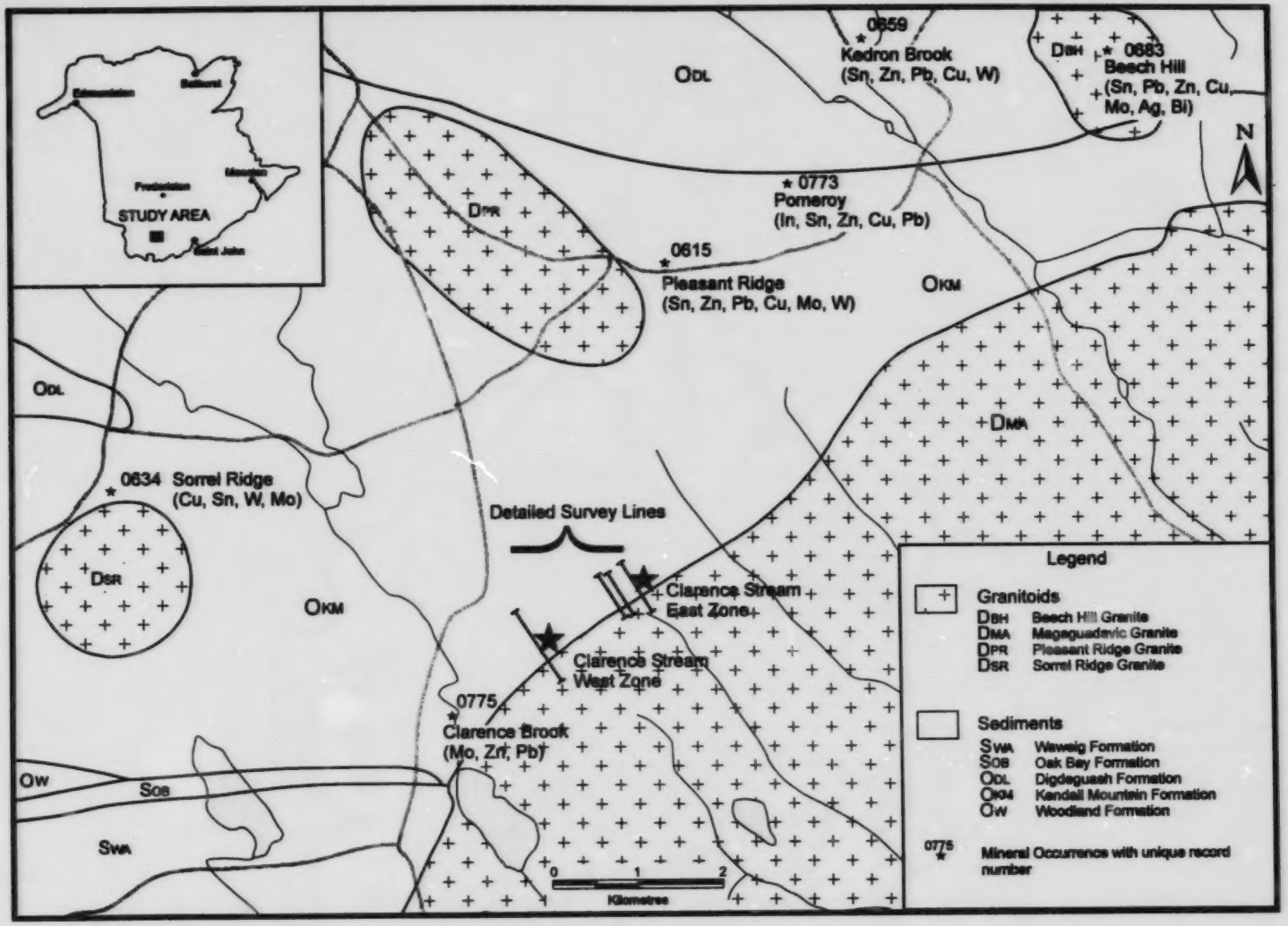

Figure 1. General geology of survey area with mineral occurrences (after Fyffe 1997 and McLeod *et al.* 1998). Also shown are survey lines (⊢—⊣) sampled for this report over known and inferred mineralization on Freewest's Clarence Stream property and sites (★) sampled for regional characterization.

Quaternary deposits observed on the Freewest property consist of a compact greyish brown or olive-brown till overlain in most areas by cobble- to boulder-sized clasts. Organic sediments have formed in depressions and poorly drained areas. These observations are consistent with regional surficial maps of the area. Rampton (1984) recorded a blanket of loamy lodgement till with a thickness varying between 0.5 m and 3 m. Lodgement till typically forms at the base of a glacial sequence and extends laterally over wide areas in a sheet 1–2 m thick. The material is poorly sorted and has a multi-modal particle distribution. Cross sections exposed by trenching reveal abundant subangular to subrounded clasts with long axes oriented in the general direction of glacial movement.

In addition to unsorted basal and lodgement tills, trenching exposed some deposits of sand, gravel, silt and clay. However, in most areas, particularly in the present and former stream valleys between ridges, boulder- and cobble-sized clasts form a layer at surface. Evidence would suggest that the lodgement till in most areas is overlain by a melt-out or basal till with finer particles removed, sorted and re-deposited elsewhere by water draining from a retreating glacier.

Vegetation cover consists mostly of mixed forest containing both recent and older clear-cut sections. Grassy meadows are found in low areas with evidence of periodic seasonal flooding. A thin layer of charcoal is present beneath the litter and humus soil horizons, indicating past fires. The maximum relief on the Freewest property is 50 m, with the highest elevation approximately 150 m above present sea level. Drainage is mainly to the southeast, into the Magaguadavic River. The northwest corner of the property drains to the northwest toward the Digdeguash River.

SOILS

Three soil orders, based on Agriculture Canada Expert Committee on Soil Survey (1987), were identified from visible characteristics observed in soil profiles of 58 sample sites in the survey area. Podzols were identified at 40 sites, brunisols at 10 sites, and gleysols at 8 sites.

Present at all sites was a litter layer (L) varying between 1 and 10 cm in thickness, and a humus (H) layer between <1 and 23 cm. A grey to white leach horizon (Ae) was present at 23 sites, and varied between 1 and 40 cm in thickness. This layer was frequently patchy or intermittent and most often noted in podzol profiles.

The following field observations were used to classify soils at sample sites.

Podzolic Order

An Fe- and Al-enriched (Bf) horizon was present that varied between 10 and 50 cm in thickness, with a minimum of 10 cm necessary to be classified as a podzol. Based on Munsell Soil Colour charts (Munsell Color Company Inc. 1990), hue was 7.5 YR or redder (generally a rusty red), and chroma higher that 3. Material had a silty feel when rubbed wet, and the texture was coarser than clay.

Brunisolic Order

Brunisols were identified by the presence of a layer of material at least 5 cm thick and only slightly altered in appearance (Bm horizon) from the underlying parent material (C horizon). A Bf horizon was

Table 1. Concentrations of Selected Elements in Rocks Sampled Adjacent to Mineralization,

Sample	Zone	Au	Au	Ag	As	Sb	B	Ba	Be	Bi	Cd	Co
Analytical method		1	4	3	5	5	5	3	3	3	3	3
Units		ppb	ppb	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
RX1002	East	67 720*	55 200*	>99 999*	1 549✲	13 283*	9	185	2	32.2✲	22.1✲	9
RX1016	West	66 283*	106 000*	55 356*	44*	12*	1	13	< 1	13.6✲	37.6✲	1
RX1001	East	59 610*	45 900*	16 421✲	2 014*	10 930*	3	162	1	13.1✲	1.0*	14
RX1004	East	18 381*	14 000*	13 014✲	4 795*	15 740*	5	438	2	14.8✲	8.8*	14
RX1015	West	16 995*	12 800*	2 636*	19 201*	1 047*	2	22	1	13.2✲	3.6*	15
RX1003	East	9 575*	7 490*	1 796*	1 623✲	13 155*	10	328	2	2.5*	2.9*	14
RX1007	East	4 811*	3 730*	1 489*	1 523✲	7 320*	2	612	3	0.8	0.9	9
RX1011	West	4 650*	3 470*	5 738✲	41 640*	7 944*	4	290	1	15.2✲	4.1*	51
RX1014	West	4 421*	3 810*	5 980✲	7 001*	471*	2	25	< 1	8.1*	9.3*	6
RX1009	East	3 144*	2 610*	7 984✲	25 486*	423*	2	80	< 1	23.5✲	65.6✲	5
RX1012	West	286✲	361✲	370	541✲	1 367*	1	100	1	1.3*	0.5	37
RX1013	West	174✲	224✲	126	501✲	170✲	2	74	1	0.1	0.4	47
RX1005	East	71*	82*	< 20	114*	14*	2	82	33*	9.9*	0.1	11
RX1017	West	35*	42*	315	78*	5*	< 1	126	1	0.6	0.6	46
UCC		1.8	1.8	53	1.8	0.26	16	609	3.1	0.13	0.1	10.8

Notes: UCC – upper continental crust (data from Reimann and Caritat 1998).
* indicates 10 to 100 times UCC; ✲ indicates 101 to 1000 times UCC; * indicates >1000 times UCC.
Analytical methods: 1 Lead collection fusion, aqua regia digestion of pill; inductively coupled plasma-emission spectrometry

either absent or less than 10 cm thick. The typical Bm horizon was only slightly different in colour from the C horizon (usually a bit redder), and of a similar composition to the underlying parent material.

Gleysolic Order

Gleysols were found in low areas beside streams or in swampy areas. The diagnostic feature of gleysols was a greyish horizon (Bg) with prominent reddish mottling. This horizon is analogous to a Bm horizon but the colours are indicative of long periods of poor drainage and periodic reduction.

GEOCHEMISTRY OF MINERALIZATION

Table 1 summarizes analytical results from 17 composite chip samples collected as part of this study from surface mineralization in the East and West Zones (Figure 2). These data are useful in determining the element association of the mineralization, and indicate which elements in surficial materials should be the focus of the geochemical interpretation. Arsenic, Sb and Ag are the most strongly enriched elements associated with the Au. To a lesser extent, Bi, Cd, Pb, S and Te are also enriched in the mineralization relative to their crustal abundances (cf. Reimann and Caritat 1998).

SAMPLING AND ANALYTICAL METHODS

Geological Survey of Canada personnel collected samples of surficial materials from 58 sites over the Freewest Clarence Stream property in southwestern New Brunswick in September 2000. An additional

Highlighting Values Elevated Relative to Average Concentrations in Upper Continental Crust

Cr 3 ppm	Cu 3 ppm	Hg 6 ppb	La 3 ppm	Mo 3 ppm	Ni 3 ppm	Pb 3 ppm	Pd 1 ppb	Pt 1 ppb	S 3 %	Se 5 ppm	Sn 2 ppm	Te 5 ppm	Th 3 ppm	U 3 ppm	V 3 ppm	W 3 ppm	Zn 3 ppm
33	154	< 5	33	0.5	19	5 257*	< 2	4	0.9*	< 0.1	5	1.85*	9	2.2	44	12	101
2	46	8	< 1.0	0.8	1	430*	< 2	< 2	0.2	0.4	< 1	0.53*	< 1	< 0.20	< 4	1	2 161*
22	48	< 5	10	0.1	16	73	7*	3	0.7*	< 0.1	1	0.31*	3	0.7	18	< 1	48
32	52	< 5	28	4.8	16	406*	2	< 2	0.9*	< 0.1	4	0.02	8	3.6	68	4	335
3	109	37	2	0.9	25	41	< 2	7	1.8*	0.6	2	0.36*	< 1	0.2	51	49*	356
34	61	< 5	23	0.4	25	133	3	8	1.0*	0.2	2	0.24*	7	1.9	74	2	209
31	42	< 5	38	0.4	11	106	11*	10*	1.1*	0.1	2	0.07*	12	2.7	73	12	50
69	196*	9	10	1.1	31	64	< 2	< 2	2.8*	1.2*	6	1.30*	1	0.3	249	8	279
8	30	< 5	1	0.3	6	191*	< 2	< 2	0.3	0.2	1	0.19*	< 1	< 0.20	13	2	520
5	31	< 5	6	2.2	5	836*	2	5	1.6*	< 0.1	2	0.14*	1	0.3	11	2	1 906*
73	107	10	15	0.9	16	16	4	7	0.8*	0.3	5	0.13*	3	0.6	336	6	144
151	30	5	8	0.3	110	11	< 2	10*	0.1	0.1	2	0.03	1	0.2	199	2	137
16	76	6	16	3.2	8	11	3	6	0.2	0.4	2	0.24*	6	4.4	95	13	36
14	46	< 5	19	1.8	22	25	2	7	1.1*	0.5	2	< .02	2	0.4	500	2	157
35	19.5	38	31.2	1.5	19.3	18.5	0.5	1.0?	0.06	0.08	4	0.005	10.5	2.7	56	1.7	57

(ICP-ES) finish on 30 g sample. **2** LiBO2 fusion / ICP. **3** Four-acid digest/inductively coupled plasma-mass spectrometry (ICP-MS) on 1g sample (As, Sb lost due to volatization). **4** Instrumental neutron activation analysis (INAA). **5** Aqua-regia digestion/ICP-MS on 1 g sample. **6** Cold vapor-atomic absorption spectrometry (CV-AAS)

11 sites were selected off the property to establish regional background levels in various sample media. Sample sites on the Freewest property were selected along four lines of a soil sample grid laid out by Freewest consisting of 25 m sampling intervals along lines spaced 50 or 100 m apart. Two lines, 4+50E and 18+00E (Figure 2), cross the strike of known mineralization identified in adjacent trenches. Although lines 15+00E and 16+00E (Figure 2) cross the inferred strike of known mineralization, samples of B-horizon soil analysed by Freewest were not anomalous, possibly because of the depth (>7 m) and nature (sandy till) of the overburden. Sampling along these two lines was carried out to determine if mineralization extends into this area and to evaluate the effectiveness of various geochemical methods (e.g., selective leaches) in a geochemically problematic environment. In most cases, Geological Survey of Canada sample sites were within 1 or 2 m of Freewest B-horizon sample sites except where site frequency was increased over the actual or inferred strike of mineralization.

At all 58 sites a sample of humus and two samples of B-horizon material were collected. In addition, at all sites a sample of the existing soil profile was taken 10 to 20 cm below surface for mobile metal ion analysis (in all cases, mobile metal ion samples were composed of material from a single soil horizon). At 24 sites a sample of the underlying till was collected and from 17 till sites a large till sample (approx. 8–10 kg) was collected. At each site, detailed field observations were recorded, including location, site characteristics (topography, vegetation, drainage), nature of the soil, till and underlying bedrock, where possible, and potential sources of contamination.

At each site the surface was cleared of leaf litter, twigs and partially decomposed material to expose the dark brown to black humus horizon. After collecting two kraft paper bags full of material by hand, the depth of the hole was extended to approximately 10–15 cm with a plastic shovel. A pair of garden

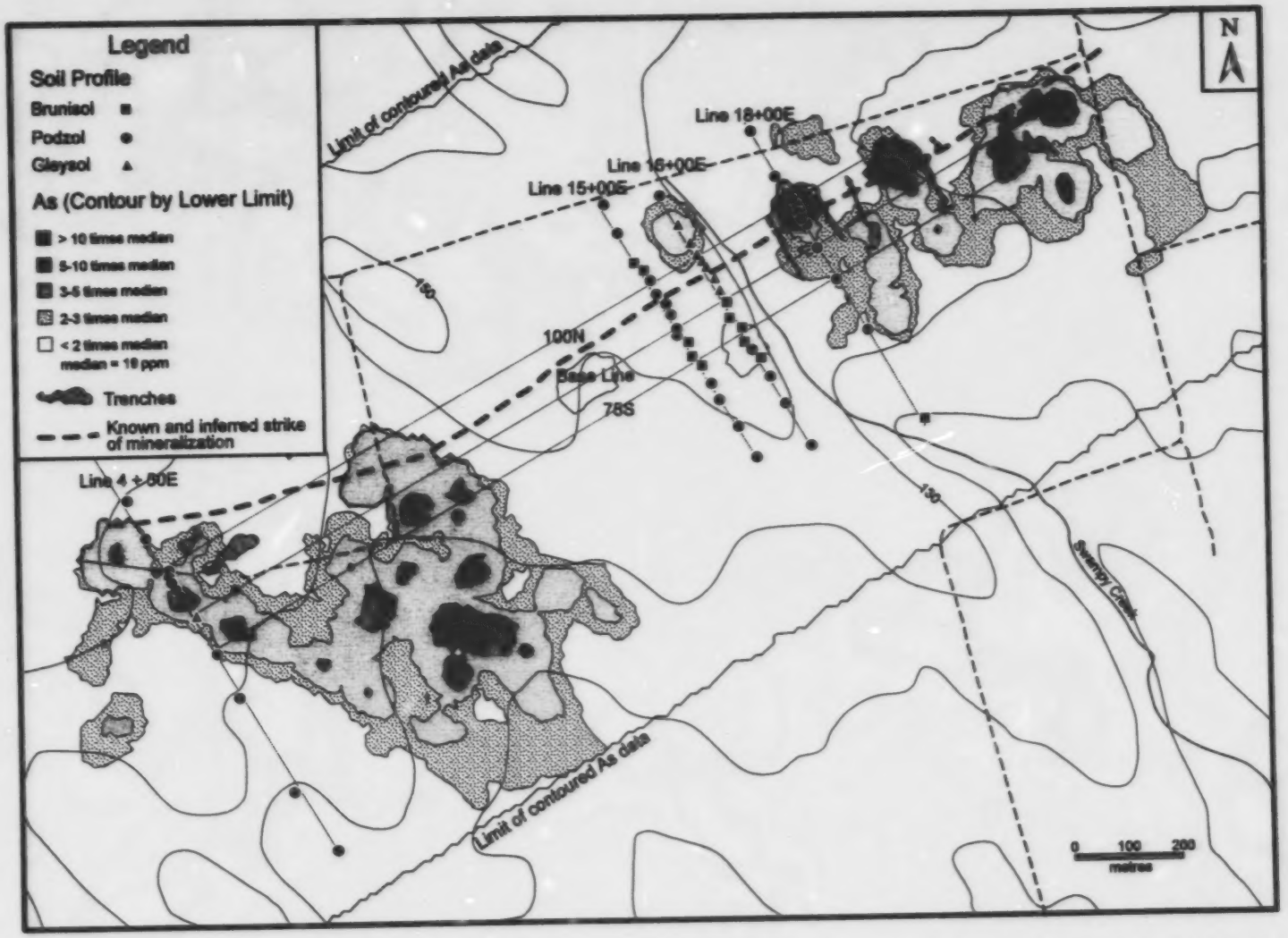

Figure 2. Detailed map of Freewest Resources Canada, Inc.'s Clarence Stream property showing contoured arsenic (As) data from one of the company B-horizon soil surveys. Also shown are the sampling grid, and location and nature of sites sampled for this report.

pruners was used to clear small roots from the hole. At this level approximately 750 g of material was collected and placed in a self-sealing plastic bag for mobile metal ion analysis. The depth of the hole was extended, if necessary, to the B-horizon and two samples collected, one for enzyme leach and one for instrumental neutron activation analysis and trace-element analysis. These samples were placed in separate kraft paper bags. To collect samples of till, the hole was extended below the level of oxidized till, taken to be below the colour change from reddish brown to brown or greenish brown. One kraft paper bag was filled with till. At sites where bulk till samples were collected, approximately 10 kg of the same material was dug out with plastic shovels and placed into a heavy-duty polyethylene bag, sealed with black electrical tape and placed into another plastic bag.

Samples were shipped to Ottawa for sample preparation. Table 2 summarizes the sample preparation procedures and analytical methods used to determine element concentrations in various sample media.

RESULTS AND DISCUSSION

Throughout the following text and related figures and tables reference is made to weak, moderate, strong and very strong anomalies. These refer to values that are: 2 to 3 times median (weak); 3.1 to 5 times median (moderate); 5.1 to 10 times median (strong); and >10 times the median (very strong). The median value calculated for an element in a given medium is considered to be a reasonable and robust estimate of background. Median values for selected elements are summarized in Table 3. The description of an anomaly as weak, strong or otherwise, although somewhat subjective, is nonetheless a useful comparison.

Geochemical response to known mineralization (lines 4+50E and 18+00E)

Figure 2 shows contoured As data from a B-horizon soil survey conducted by Freewest Resources Canada, Inc. overlain by the lines sampled as part of this study. These lines do not parallel the direction of glacial dispersal as indicated by the As data in Figure 2, and lines 4+50E and 18+00E do not cross the central zones of mineralization. However, the down-ice extent of the glacial dispersal train in B-horizon soils can be estimated from Freewest soil data. If >2 times the median is taken as a threshold value then the B-horizon anomaly in As extends approximately 800 m from the West Zone and approximately 300 m from the East Zone. A more extensive anomaly would be expected in the tills and preliminary work by Pronk and Boldon (2000) indicates a till dispersal train in the order of 2.5 to 3.0 km.

The Au and As distributions in the various media sampled as part of this study are summarized in Figures 3 and 4. There is a strong Au response over lines 4+50E and 18+00E in the interval from the baseline to 100N, coinciding with the known mineralization. All media give a similar strong to very strong response for Au except for the enzyme leach data. Bajc (1998) notes that metallic Au and Hg are not liberated by the enzyme reaction. Arsenic shows a response similar to Au over lines 4+50E and 18+00E.

Table 4 summarizes the data from a total of four sites (along lines 4+50E and 18+00E) directly over the strike of known mineralization. The analytical values are shown for nine elements in each of the five media. Based on the ratio of the elemental concentration to the median value, a score of 0 to 4 (represented by symbols) is assigned. Evaluation of Table 4 suggests the following:

1. Overall, Au is the best indicator of the mineralization (score = 51) followed by As, Sb and Ag. Much less indicative are Bi, Cd, Pb, Te and Zn.

Table 2. Summary of Analytical Procedures Used to Determine Concentrations of Elements in Humus, B-horizon Soil, and Till in the Study Area

Sample Media	Sample Preparation	Fraction for Analysis	Analytical Method
Humus	Drying, sieving	<177 µm	ICP-MS (I), INAA, F, LOI, Sn
B-horizon soil	Drying, sieving	<63 µm	ICP-MS (I), INAA, F, LOI, Sn
MMI (10–20 cm depth)	None	500 g split	MMI analysis (precious metals and pathfinders packages)
Enzyme leach (B-horizon)	Drying, sieving	<250 µm	ICP-MS (II)
Till	Drying, sieving	<63 µm	-INAA, ICP-MS (I), F, LOI, Sn
		<180 µm	-ICP-MS (I), F, Sn
		<850 µm to >180 µm	-ICP-MS (I), F, Sn
Bulk till	Shaker table, heavy liquid separation, magnetic separation	Heavy mineral concentrate (density > 3.2)	100 grain mineral count (0.25 to 0.50 fraction); INAA, ICP-MS (I), F, Sn

Notes: **ICP-MS (I)** – Aqua-regia digestion/inductively coupled plasma-mass spectrometry (ICP-MS): Au, Ag, Al, As, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Hg, Ga, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Se, Sr, Te, Th, Ti, Tl, U, V, W, Zn.
ICP-MS (II) – Selective leach/ICP-MS: Li, Be, V, Mn, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ru, Pd, Ag, Cd, In, Sn, Sb, Te, I, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Pt, Au, Tl, Pb, Bi, Th, U.
INAA – Inductively coupled neutron activation analysis: As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Na, Rb, Sb, Sc, Sm, Ta, Tb, Th, U, W, Yb.
MMI – mobile metal ion: **Digest B, Precious Metals** – Au, Ag, Ni, Co, Pd; **Digest F, Pathfinders** – As, Sb, Hg, Mo, Se, Fe.
Specific methods: F – ion specific electrode, LOI – loss on ignition at 500° C, Sn – atomic absorption spectrometry (AAS)

Table 3. Median Values for Selected Elements in Humus, B-horizon Soils and Till Determined by Various Analytical Methods

	Ag	As	Au INAA	Bi	Cd	F ISE*	Mo	Mn	Sb	U	W INAA	Zn
	ppb	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm		ppm
Humus (n=69)	577	8.4	3.0	0.39	0.67	90	1.1	192	0.9	0.3	1.0	64
B-horizon (n=66)	195	29	3.0	0.47	0.14	240	1.3	164	1.1	0.9	2.0	55
MMI (n=58)	6.4	11**	<0.1	n/a	n/a	n/a	<1**	n/a	6**	n/a	n/a	n/a
Enzyme leach (n=58)	<0.2	11**	<0.05	<0.8**	3.8*	n/a	<1**	1815**	4.6**	1.2**	<1**	1305**
Till (n=33)	85	38	4.0	0.62	0.15	240	1.2	364	1.9	1.0	2.0	66
Till HMCs (n=25)	118	164	14.6	6.1	0.40	1290	6.3	1416	12.6	3.7		86

Notes: Digestions are by: (1) aqua regia for all elements except Au and W (INAA); (2) MMI, enzyme leaches.
Abbreviations: HMC – heavy mineral concentrate; INAA – instrumental neutron activation analysis; MMI – mobile metal ion.
* Ion selective electrode; ** ppb

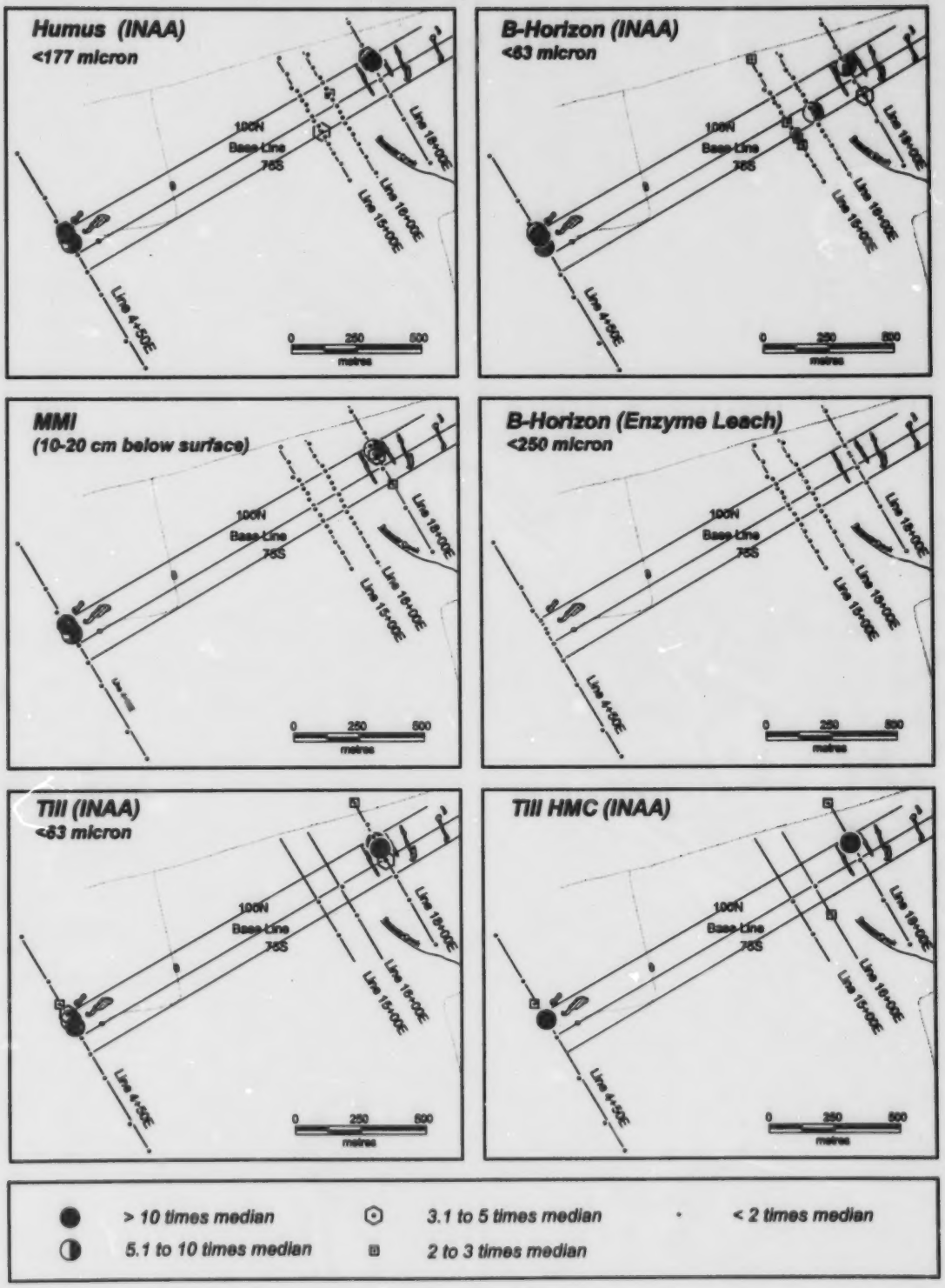

Figure 3. A comparison of gold concentrations in different size fractions of various sample media, determined by instrumental neutron activation analysis (INAA) and by two types of proprietary selective digestions, enzyme leach and mobile metal ion (MMI). HMC is heavy mineral concentrate.

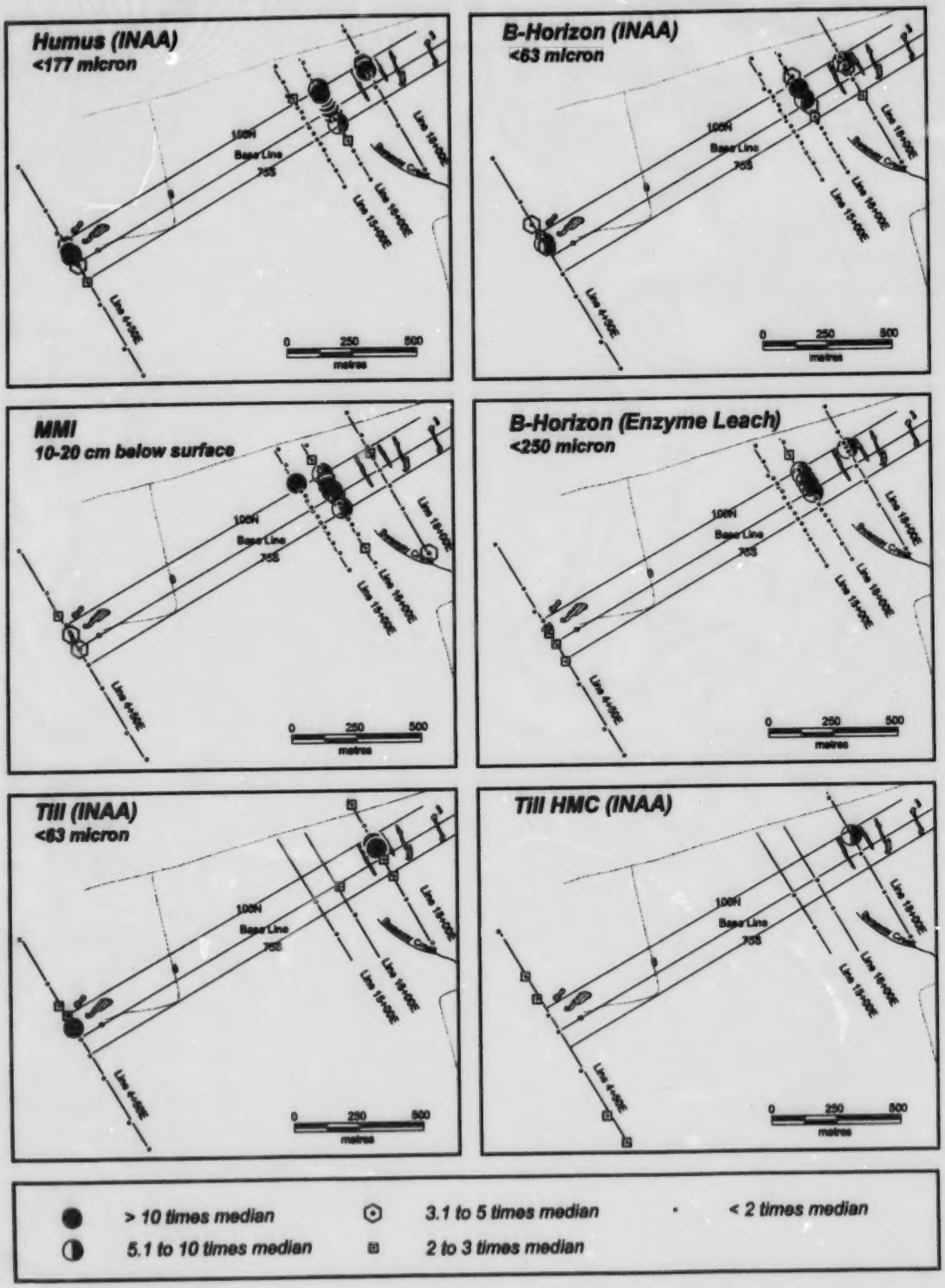

Figure 4. A comparison of arsenic concentrations in different size fractions of various sample media, determined by instrumental neutron activation analysis (INAA) and by two types of proprietary selective digestions, enzyme leach and mobile metal ion (MMI). HMC is heavy mineral concentrate.

2. Based on the Au, Ag, As and Sb data, elements available for all media, till gives the best response to mineralization (score = 40). B-horizon by aqua regia works almost as well (score = 36) followed by humus by aqua regia, mobile metal ion and enzyme leach.
3. The strongest anomaly contrast ratio (78.9) occurs for Sb in till along line 18+00E. Of the 15 ratios (value to median) with a value >10 (very strong anomaly), 9 are from till, 3 from B-horizon and 3 from humus.

The distribution of Au in till shows the strongest and most consistent response to mineralization on the Clarence Creek property. However, considering the relative ease of collection of B-horizon material, it should be the medium of choice for similar property-scale geochemical surveys in the area. In addition to Au, the distributions of As, Sb and Ag in till or B-horizon soils should be considered. Additional data are required to determine the down-ice extent to which these two media reflect mineralization and whether or not till is a better choice for a more regional scale survey.

Response along lines 15+00E and 16+00E

One of the objectives of sampling lines 15+00E and 16+00E was to evaluate, based on geochemistry, whether or not the mineralization extends into this area. Table 5 shows the geochemical response of As, Au, Sb, Mo, U, Fe and Mn at four sites along each sample line over or adjacent to known or inferred mineralization. Data from line 15+00E as summarized in Table 5 and Figures 3 and 4 show no significant anomalies along this line, suggesting that surface or near-surface mineralization does not extend to this line and that mobile metal ion and enzyme leach digestion methods are not detecting buried mineralization.

In comparison to line 15+00E, there is a very strong geochemical response along line 16+00E, notably for As and Sb (Table 5). However, although a component of this anomaly may be related to clastic dispersion from nearby mineralization it is likely that the major component is hydromorphic in origin, resulting from scavenging by hydrous Fe and/or Mn oxides. The formation of soil anomalies in seepage zones resulting in non-significant or false anomalies is well known in the applied geochemical literature. The following observations suggest that the anomaly along line 16+00E is probably, to a significant extent, related to this mechanism.

1. Line 16+00E between 150N and 75S occurs in a topographic low. Gleysol is the dominant soil type noted along this section compared to elsewhere where podzols and brunisols were observed (c.f. Figure 2). Moisture content as noted in field notes is saturated to wet, compared to dry or moist for all other sample sites.
2. Mn and, to a lesser extent, Fe are highly enriched in samples from this line. For example, Mn values in the B-horizon of 6899 and 2794 ppm occur at stations 88N and 75N, respectively (Table 5), compared to a background value of 164 ppm. Similar enrichments are also evident in the humus and enzyme leach data.
3. The absence of an anomalous Au response, which is a relatively immobile element in the surficial environment.
4. Strong to very strong anomalies in Mo and U. These elements are moderately to highly mobile in the surficial environment, are known to be scavenged by Mn and/or Fe, but are not enriched in the known mineralization of the Clarence Stream property (cf. Table 1). Figure 5 shows a very strong Mo response along 16+00E compared to the other lines. It is noteworthy that a restricted Mo anomaly on line 4+50E near the base line is the only site, other than along line 16+00E, identified as having a gleysol soil profile.

Table 4. Concentrations of Selected Pathfinder Elements Determined by Various Analytical Methods in Humus, B-horizon Soils and Tills at Two Sites Over Mineralization, Highlighting Analytical Values that are Elevated Relative to Median Values.

	Station	Line 18+00E 75N	Line 18+00E 50N	Line 4+50E 75N	Line 4+50E 50N	Sum of scores/element (Max = 16 per 2 lines)	
Ag	MMI	6.2✱	5.4✱	1.8	2.1✱	7	
	Enzyme Leach	1.0	1.0	1.0	1.7	0	
	Humus	2.4✱	1.7	0.8	0.9	1	**16**
	B-horizon	4.7✲	1.7	3.7✲	2.3✱	5	
	Till	1.8	0.8	2.0	6.5✱	3	
As	MMI	2.7✱	0.7	0.5	1.1	1	
	Enzyme Leach	6.6✱	1.3	2.1✱	2.1✱	5	
	Humus	15.6■	0.9	2.2✱	6.8✱	8	**35**
	B-horizon	6.9✱	3.1✲	3.8✲	4.4	9	
	Till	15.2■	30.3■	1.6	27.0■	12	
Au	MMI	7.6✱	6.0✱	7.9✱	8.1✱	12	
	Enzyme Leach	1.0	1.0	1.0	1.0	0	
	Humus	21.0■	1.7	6.7✱	8.3✱	10	**51**
	B-horizon	6.0✱	5.3✱	16.0■	47.0■	14	
	Till	45.0■	47.5■	7.8✱	35.0■	15	
Bi	MMI	n/a	n/a	n/a	n/a	n/a	
	Enzyme Leach	4.2✲	1.0	1.0	1.0	2	
	Humus	1.4	1.2	1.2	1.4	0	**5**
	B-horizon	1.0	1.3	0.5	0.7	0	
	Till	0.8	5.4✱	0.6	0.9	3	
Cd	MMI	n/a	n/a	n/a	n/a	n/a	
	Enzyme Leach	1.1	1.8	0.7	1.4	0	
	Humus	1.1	3.9✲	0.9	1.1	2	**7**
	B-horizon	1.5	1.6	1.1	1.1	0	
	Till	17.8■	3.0✱	1.9	1.5	5	
Pb	MMI	n/a	n/a	n/a	n/a	n/a	
	Enzyme Leach	1.6	1.3	0.8	1.4	0	
	Humus	0.9	1.5	1.5	1.5	0	**2**
	B-horizon	1.4	1.4	1.0	1.2	0	
	Till	1.7	3.5✲	1.3	1.1	2	
Sb	MMI	2.8✱	2.3✱	0.3	1.0	2	
	Enzyme Leach	4.7✲	2.6✱	1.7	2.3✱	4	
	Humus	35.4■	5.9✱	1.6	2.0	7	**31**
	B-horizon	14.3■	4.2✲	2.0	4.5✲	8	
	Till	78.9■	24.2■	1.9	4.0✲	10	
Te	MMI	n/a	n/a	n/a	n/a	n/a	
	Enzyme Leach	1.0	1.0	1.0	1.0	0	
	Humus	1.5	2.5✱	1.0	1.5	1	**3**
	B-horizon	1.0	1.0	1.3	2.0	0	
	Till	1.0	3.5✲	0.8	1.0	2	
Zn	MMI	n/a	n/a	n/a	n/a	n/a	
	Enzyme Leach	1.0	0.9	1.1	0.8	0	
	Humus	1.5	1.1	0.9	1.0	0	**3**
	B-horizon	1.1	1.1	0.7	1.0	0	
	Till	5.6✱	1.9	1.0	1.0	3	

Note: A value of 0 to 4 is assigned to each analytical result depending on its position relative to the median; total scores are shown at right. MMI is mobile metal ion.

Score:		
0		≤2 times median
1	✱	2.1– 3 times median
2	✲	3.1 – 5 times median
3	✱	5.1 – 10 times median
4	■	>10 times median

Combined score for Au, Ag, As, Sb in each medium	
MMI	22
Enzyme Leach	9
Humus	26
B-horizon	36
Till	40

Table 5. A Comparison of Geochemical Response of Selected Elements at Four Sites Along Survey Lines Over Known or Inferred Mineralization, Highlighting Analytical Values that are Elevated Relative to Median Values

Station	Line 4+50E				Line 15+00E				Line 16+00E				Line 18+00E			
	88N	75N	63N	50N	88N	63N	38N	13N	88N	75N	50N	25N	88N	75N	62.5N	50N
As																
Humus	37✲	18✱	109■	57✱	7.5	4.1	4.5	7.2	167■	96■	217■	96■	399■	131■	11	8
Enzyme Leach [b]	19	23✱	24✱	23✱	4.6	8.0	5.4	7.3	55✲	72✱	109✱	97✱	16	72✱	11	14
MMI [b]	8	5	36✲	12	15	10	14	9	8	33	312■	74✱	5	30	6	8
B-horizon–ICP [m]	80✱	110✲	174✱	127✲	19	24	18	14	255✱	648■	62✱	182✱	61✱	200✱	37	89✲
Till	n/a	61	n/a	1 026■	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	577■	n/a	1 150■
Till (HMC)	n/a	150	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1287✱	n/a	n/a
Au																
Humus–INAA [b]	35■	20✱	29✱	25✱	<2.0	3	<2.0	3	4	<2.0	8.0✱	<2.0	60■	63■	6.0✱	5
Enzyme Leach [b]	0.1✱	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MMI [b]	4.2■	0.6✱	0.9✱	0.6✱	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.6✱	<0.1	0.5✲
B-horizon–INAA [b]	100■	24✱	26✱	70■	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	9.0✱	19✱	8.0✱
Till	n/a	31✱	n/a	140■	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	180■	n/a	190■
Till (HMC)	n/a	175■	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40 282■	n/a	n/a
Sb																
Humus	1.8✱	1.6	3.0✲	2.0✱	0.86	0.93	0.68	0.74	2.0✱	1.8	4.6✱	11■	112■	35■	4.2✲	5.9✱
Enzyme Leach [b]	8.2	8	17✲	10.8✱	1.95	4.58	3.26	3.9	17✲	78■	653■	233■	4.9	22✲	8.2	12✱
MMI [b]	5	2	24✲	6.0	6	8	9	4	6	72■	168■	237■	3.0	17✱	6.0	14✱
B-horizon–ICP [m]	3.0✱	2	6.0✱	5.0✲	1.1	1.2	0.8	0.7	3.2✱	47■	14■	36■	1.4	16■	4.0✲	4.6✲
Till	n/a	3.7	n/a	7.5✲	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	150■	n/a	46■
Till (HMC)	n/a	12.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	239■	n/a	n/a
Mo																
Humus-INA	1.7	1.4	1.6	2.5✱	0.87	0.96	0.76	1.13	32■	14■	44■	35■	1.3	0.9	0.9	1.2
Enzyme Leach [b]	<1.0	<1.0	2.0✱	<1.0	<1.0	1.36	<1.0	<1.0	64■	47■	111■	222■	<1.0	<1.0	<1.0	<1.0
MMI [b]	<1.0	<1.0	2.0✱	<1.0	2.0✱	1	<1.0	<1.0	<1.0	3.0✱	43■	42■	<1.0	<1.0	<1.0	<1.0
B-horizon–ICP [m]	2	1	9.0✱	4.0✲	1	1	0.8	0.9	43■	76■	12✱	36■	1.3	1.5	1.0	1.5
Till	n/a	1.2	n/a	4.3✲	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.3	n/a	1.8
Till (HMC)	n/a	3.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.5	n/a	n/a
U																
Humus	0.1	0.3	0.2	0.3	0.2	0.2	0.1	1.3✲	5.2■	5.5■	2.3✱	4.1■	0.6✱	0.3	0.1	0.2
Enzyme Leach [b]	1.2	0.9	0.8	0.8	0.862	0.946	1.03	1.03	5.5✱	5.5✱	4.7✱	4.9✱	1.06	1.65	1.15	1.12
MMI [b]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B-horizon	1	1	1	1	0.8	1	0.8	0.7	15.5■	27.3■	13.2■	17.7■	0.8	0.9	0.8	0.8
Till	n/a	0.8	n/a	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.5	n/a	2.5✲
Till (HMC)	n/a	1.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.3	n/a	n/a
Fe																
Humus	0.5	0.6	0.7	1.1	0.7	0.3	0.3	0.9	2.2✱	2.2✱	3.6✲	1.8	0.96	1.33	0.24	0.32
Enzyme Leach	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MMI [b]	112	93	106	64	408✲	202✱	157	90.8	17.7	40	102	103	83.5	53	97.3	50.6
B-horizon–ICP(%)	5	3	3	2	3.1	3.6	2.2	2.2	5.1	6.1✱	1.4	3.3	3.7	3.3	3.1	3.5
Till	n/a	2.1	n/a	2.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.2	n/a	3.8
Till (HMC)	n/a	6.2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5.2	n/a	n/a
Mn																
Humus	122	138	1 008✱	213	62	50	90	62	22 516■	453✱	18 565■	1 670✱	171	280	49	167
Enzyme Leach [b]	1 350	758	4 950✱	1 780	819	4 300✱	1 370	1 390	105 000■	11 900✱	44 400■	25 100■	1 090	704	514	1 320
MMI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
B-horizon [m]	71	62	195	91	171	160	114	194	6 899■	2 794■	701✲	435✱	74	124	58	143
Till	n/a	243	n/a	227	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	839✱	n/a	1 021✱
Till (HMC)	n/a	597	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3 419✱	n/a	n/a

Note: A value of 0 to 4 is assigned to each analytical result depending on its position relative to the median. Abbreviations: ICP – inductively coupled plasma spectrometry, INAA – instrumental neutron activation analysis, HMC – heavy mineral concentrate, MMI – mobile metal ion.

[b] ppb; [m] ppm

Score:		
0		≤2 times median
1	✱	2.1 – 3 times median
2	✲	3.1 – 5 times median
3	✱	5.1 – 10 times median
4	■	>10 times median

Lithogeochemical data in Table 1 indicate that rocks sampled along the strike of known mineralization are elevated in Au, Ag, As and Sb relative to average crustal values. However, values of Mo and U at or below average crustal abundances are noted for most samples. In soil materials sampled in these poorly drained areas, Mn, Mo and U concentrations are greatly elevated (Table 5). The absence of anomalous concentrations of Au in soil materials from poorly drained sites along line 16+00E, and the presence of gold in soils sampled directly over mineralization, suggests that Mn is concentrating relatively mobile elements in wet areas down slope from mineralization in a reducing environment. More work is required to determine the cause of the anomalous concentrations of relatively mobile elements at water-saturated sites along line 16+00E.

With the available data, it is not possible to determine the extent to which the line 16+00E anomaly represents clastic (primary) versus secondary (hydromorphic) dispersion and/or enrichment related to scavenging. However, limited evidence suggests that the anomalous response in analytical data from gleysols on line 16+00E could represent a displaced or false anomaly. In the evaluation and interpretation of any soil survey it is important to recognize possible hydromorphic anomalies. Often they are stronger and more extensive than associated primary anomalies but identifying the source, which may be hundreds of metres away, can be much more difficult.

Topaz in Heavy Mineral Concentrates

Heavy mineral concentrates were prepared from bulk till samples collected from 17 sites along the four Freewest lines and nine regional sites. An initial 100-mineral grain count was completed for each sample on a portion of the >0.25 to <0.50 mm fraction. The major components identified include garnet, epidote, hornblende, hematite and pyrite, which combined generally accounted for more than 90% of the sample.

Three samples collected from lines 15+00E and 16+00E (Figure 6), had topaz contents in the heavy mineral concentrates greater than 25%. In comparison, no topaz grains were identified in samples along line 4+50E, and four of the five samples from line18+00E had no topaz, while the fifth sample had only 2% topaz. As expected, the fluorine values for the three heavy mineral concentrate samples with abundant topaz were highly anomalous (Table 6). However, the F content of the till sample (<63 μm fraction) collected from the same site was not notably anomalous. Similarly, F concentrations along line 15+00E did not show any anomalous pattern. Sites with elevated levels of F in the B-horizon and humus along line 16+00E are offset from the heavy mineral concentrate anomaly and are considered to be of hydromorphic origin, as outlined in the previous section.

Visual examination of the heavy mineral concentrates revealed that some of the topaz grains were relatively coarse, greater than 0.25 mm. This suggested that the lack of F response in media other than the heavy mineral concentrates could be related to the size fraction analyzed. To test this, <180 μm and <850 to 180 μm fractions were prepared from 12 selected till samples, including the three with a high topaz content. Table 6 summarizes the results of the F analysis of the different till size fractions and associated heavy mineral concentrates. It is evident from Table 6 that coarser size fractions (<180 μm and <850 to 180 μm) of the till do not reflect the heavy-mineral-concentrate fluorine anomaly any better that the original <63 μm till data. The heavy mineral concentrate fraction of the till is the only combination of medium and fraction that delineates the anomalous topaz distribution. Copper, Sn, and W data are also shown (Table 6) and are not notably anomalous, even in the three heavy mineral concentrate samples with the high topaz contents.

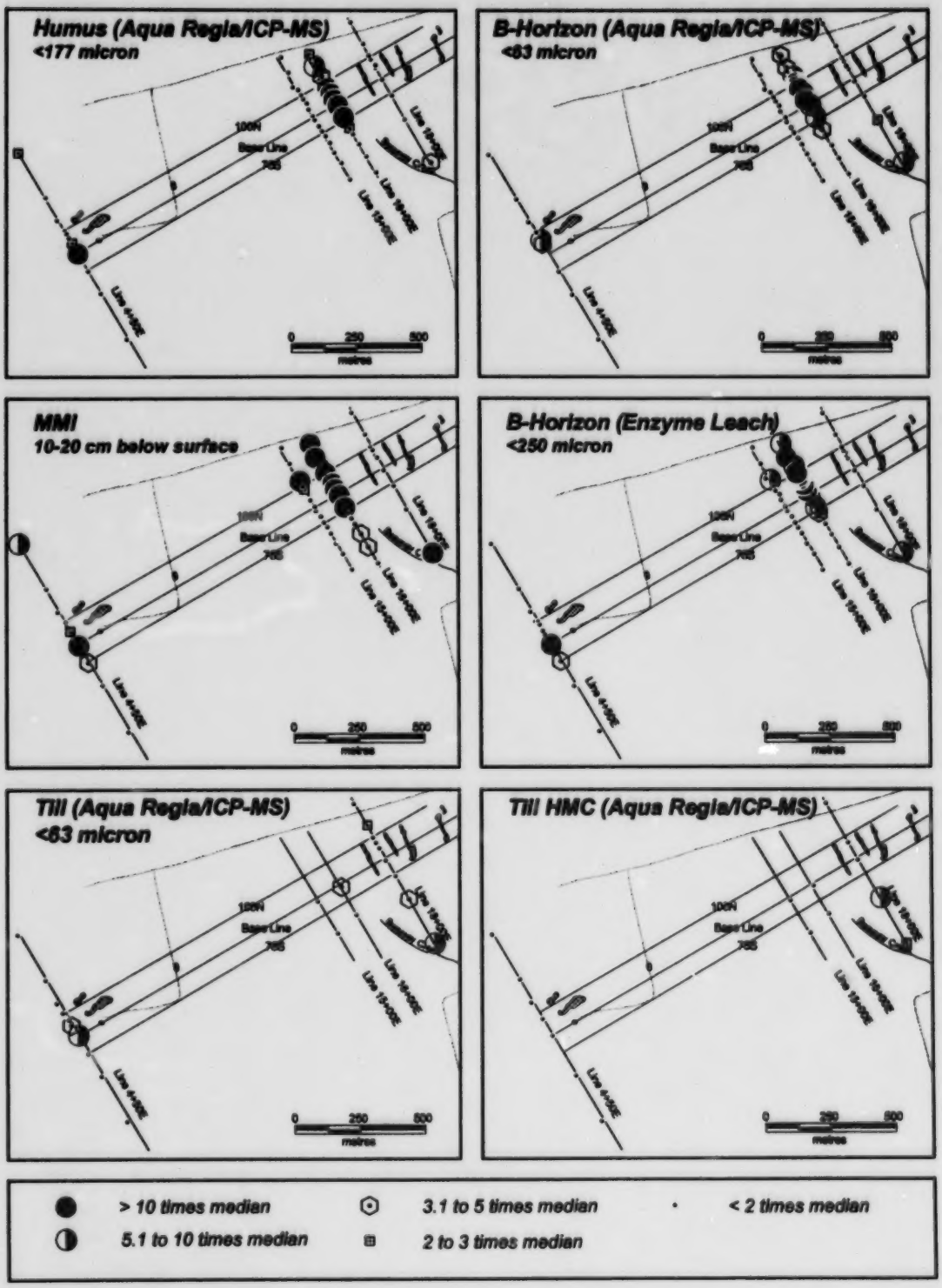

Figure 5. A comparison of molybdenum concentrations in different size fractions of various sample media, determined by instrumental neutron activation analysis (INAA) and by two types of proprietary selective digestions, enzyme leach and mobile metal ion (MMI). ICP-MS is inductively coupled plasma-mass spectrometry. HMC is heavy mineral concentrate.

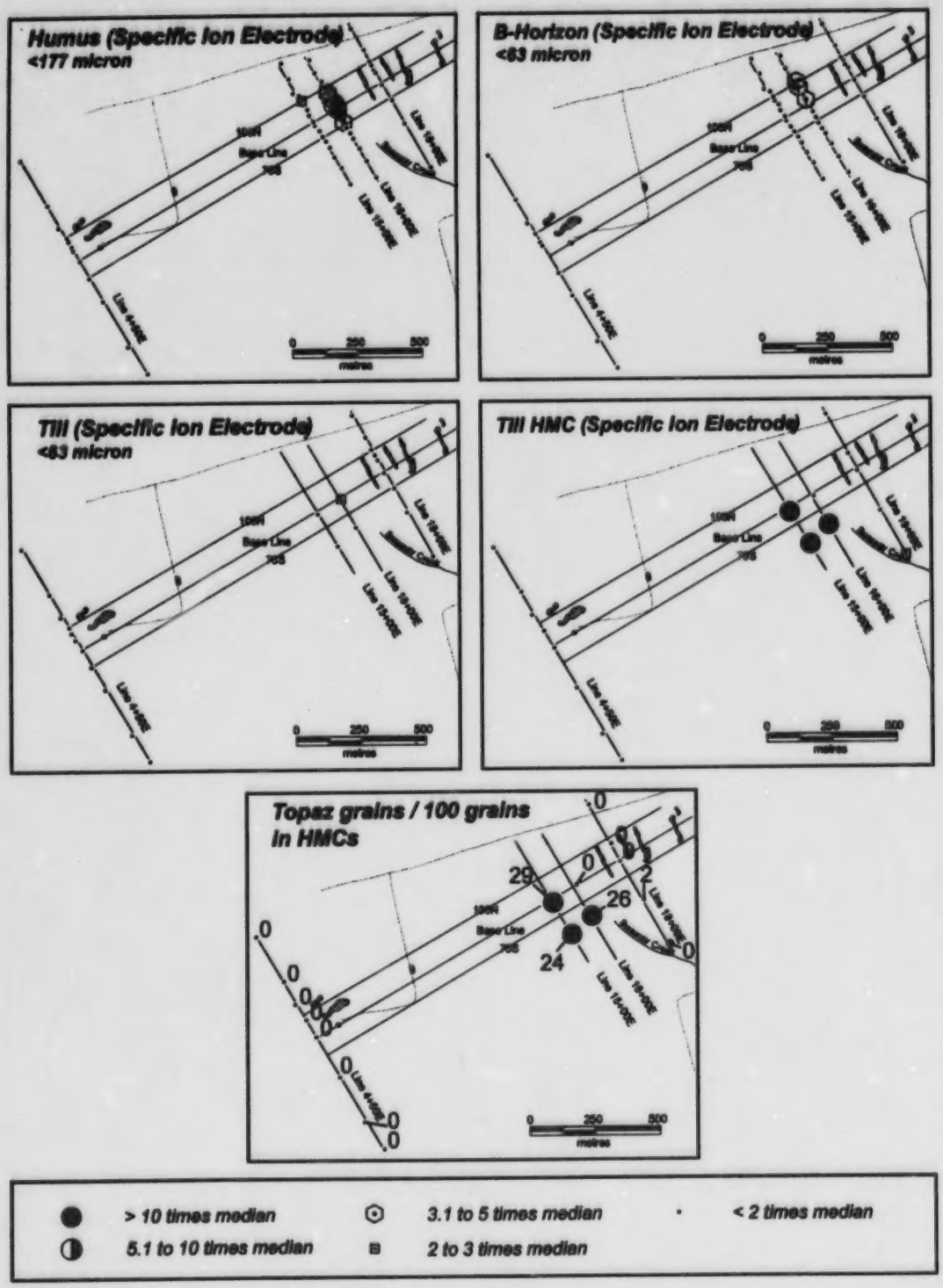

Figure 6. Proportional spot plots of fluorine concentrations in humus, B-horizon soil, and two size fractions of till, determined by instrumental neutron activation analysis. Shown for comparison is a plot of topaz grains in representative samples of heavy mineral concentrate (HMC) from till.

Table 6. A Comparison of the Geochemical Response of F, Cu, Sn and W in Four Fractions of Till from Selected Sites Along Four Survey Lines, Shown with the Number of Topaz Grains Observed in Representative Samples of Heavy Mineral Concentrate (HMC), Illustrating the Lack of Response of the Selected Elements in All but the Heavy Mineral Concentrate Fraction of Till

				F (ppm)				Cu (ppm)				Sn (ppm)			W (ppm)	
Soil Site	Line	Station	Topaz grains	HMC	<840 >177	<177	<63	HMC	<840 >177	<177	<63	HMC	<177	<63	HMC	<63
SL1017	04+50E	450N	0	1 380	130	210	200	189	14	19	19	64	2	5	1	2
SL1012	04+50E	75N	0	580	240	210	210	59	23	27	28	136	2	7	2	3
SL1020	04+50E	BL	0	1 020	240	220	210	6	11	10	10	30	2	3	1	2
SL1022	04+50E	500S	0	1 330	190	210	170	195	21	25	24	164	8	3	10	3
SL1054	15+00E	12.5S	29	32 000	410	320	190	52	13	17	18	279	3	3	4	2
SL1059	15+00E	150S	24	28 300	370	300	180	107	16	23	20	n/a	2	5	2	3
SL1036	16+00E	BL	0	2 530	480	730	700	11	10	17	14	178	5	6	48	2
SL1041	16+00E	125S	26	33 000	320	290	290	75	15	19	17	730	7	3	6	2
SL1005	18+00E	250N	0	1 540	240	250	210	78	17	24	26	456	3	7	4	3
SL1001	18+00E	75N	0	360	350	270	400	53	47	45	43	67	2	8	2	4
SL1008	18+00E	BL	0	1 290	180	210	160	90	16	23	18	430	4	4	15	2
SL1011	18+00E	375S	0	3 080	510	640	390	23	9	15	14	229	3	9	12	18

Note: Grain sizes in microns.

Topaz is a common mineral associated with greisen zones. Greisen zones and topaz-bearing rocks are known in the study area and are associated with several satellite intrusions of the Pomeroy Intrusive Suite (e.g., Pleasant Ridge Stock) along the northern edge of the Magaguadavic Granite (McLeod 1990; Ruitenberg and Fyffe 1991). Although this would be a possible source of the topaz, the distance to the Pleasant Ridge Stock (approx. 3.0 km to the north-northwest) and the high concentration at the three sites, rather than a more uniform distribution as would be expected from a relatively distal source, suggests a relatively local hitherto unknown source.

These topaz and F data illustrate the importance of doing orientation work in an area before undertaking a systematic survey. Results from orientation studies are used to determine optimum survey parameters such as medium, fraction and analytical procedure. The data for this area suggests that the heavy mineral concentrate fraction of tills is particularly useful in detecting anomalous topaz concentrations that may be related to greisen zones, more so than other media and grain-size fractions considered.

CONCLUSIONS

The confirmation of gold potential in the intrusion-related contact metamorphic aureole surrounding the Saint George Batholith has already led to a significant increase in exploration and staking activity over a wide area of potential mineralization. The following observations are considered relevant to prospectors and exploration companies carrying out geochemical surveys.

1. Au, As, Sb and Ag appear to be the best pathfinder elements to gold mineralization, but care must be taken to ensure that As and Sb are not reflecting displaced or false anomalies caused by hydromorphic transport of elements.

2. While unoxidized till provides the best geochemical contrast in anomalous to background values, B-horizon soil provides similar contrast and is a more practical material for property-scale geochemical exploration.

3. An aqua regia digestion/ICP-MS multi-element analysis is a reliable, effective analytical procedure.

4. Concentrations of topaz grains present only in the heavy mineral concentrate fractions of some tills indicate the presence of hitherto unmapped local greisen zones. Concentrations of Cu, Sn, and W at these sites are not notably anomalous, suggesting that significant economic Sn–W mineralization is not associated with these zones.

The observations presented in this paper should provide prospectors and exploration companies with guidelines to increase the effectiveness of both property- and regional-scale geochemical surveys in similar areas of New Brunswick.

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REGIONAL SIGNIFICANCE OF GRAPTOLITES FROM THE DIGDEGUASH FORMATION OF SOUTHWESTERN NEW BRUNSWICK †

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Graptolites discovered in the Digdeguash Formation during a geological survey of the South Oromocto Lake area in southwestern New Brunswick substantiate the regional separation of the dark argillite division of the now abandoned Charlotte Group into the Ordovician Cookson Group and Silurian Digdeguash Formation. The graptolites are Early Silurian in age and belong to the *Coronograptus cyphus* Zone of the upper Rhuddanian Stage within the Llandoverian Series, essentially the same age as the Hayes Brook beds underlying the Fredericton Trough of central New Brunswick. Previous lithological assignment of strata in the South Oromocto Lake area to the relatively shallow-water Waweig Formation of the Mascarene Basin is effectively ruled out by the presence of this deep-water fauna.

Des graptolites découverts dans la Formation de Digdeguash au cours d'un relevé géologique réalisé dans le secteur du lac South Oromocto dans le Sud-Ouest du Nouveau-Brunswick corrobore la séparation régionale de la section d'argilite foncée du groupe maintenant abandonné de Charlotte, à l'intérieur du groupe ordovicien de Cookson et de la Formation silurienne de Digdeguash. Les graptolites remontent au Silurien inférieur et font partie de la zone *Coronograptus cyphus* de l'étage du Rhuddanien supérieur dans la série du Llandovery, c.-à-d. qu'ils ont un âge essentiellement identique aux strates du ruisseau Hayes sous-jacentes à la dépression de Fredericton, dans le centre du Nouveau-Brunswick. La présence de cette faune de grands fonds exclut effectivement le rattachement lithologique antérieur des strates du secteur du lac South Oromocto à la Formation de fonds relativement peu profonde de Waweig du bassin Mascarene.

INTRODUCTION

A large roof pendant of sedimentary rocks within the Saint George Batholith of the South Oromocto Lake area was mapped in the summer of 2000 (Figure 1). The stratigraphic relationship of the rocks in the roof pendant to those outside of the Batholith have proved difficult to decipher due to a combination of factors including poor exposure, cordierite-hornfels grade of metamorphism, complex structure, and lack of fossils. Freewest Resources Canada Inc. has recently discovered significant gold mineralization in the Clarence Stream area along the faulted contact between the Ordovician St. Croix Terrane and Silurian

† New Brunswick Geological Surveys Branch ordinary budget

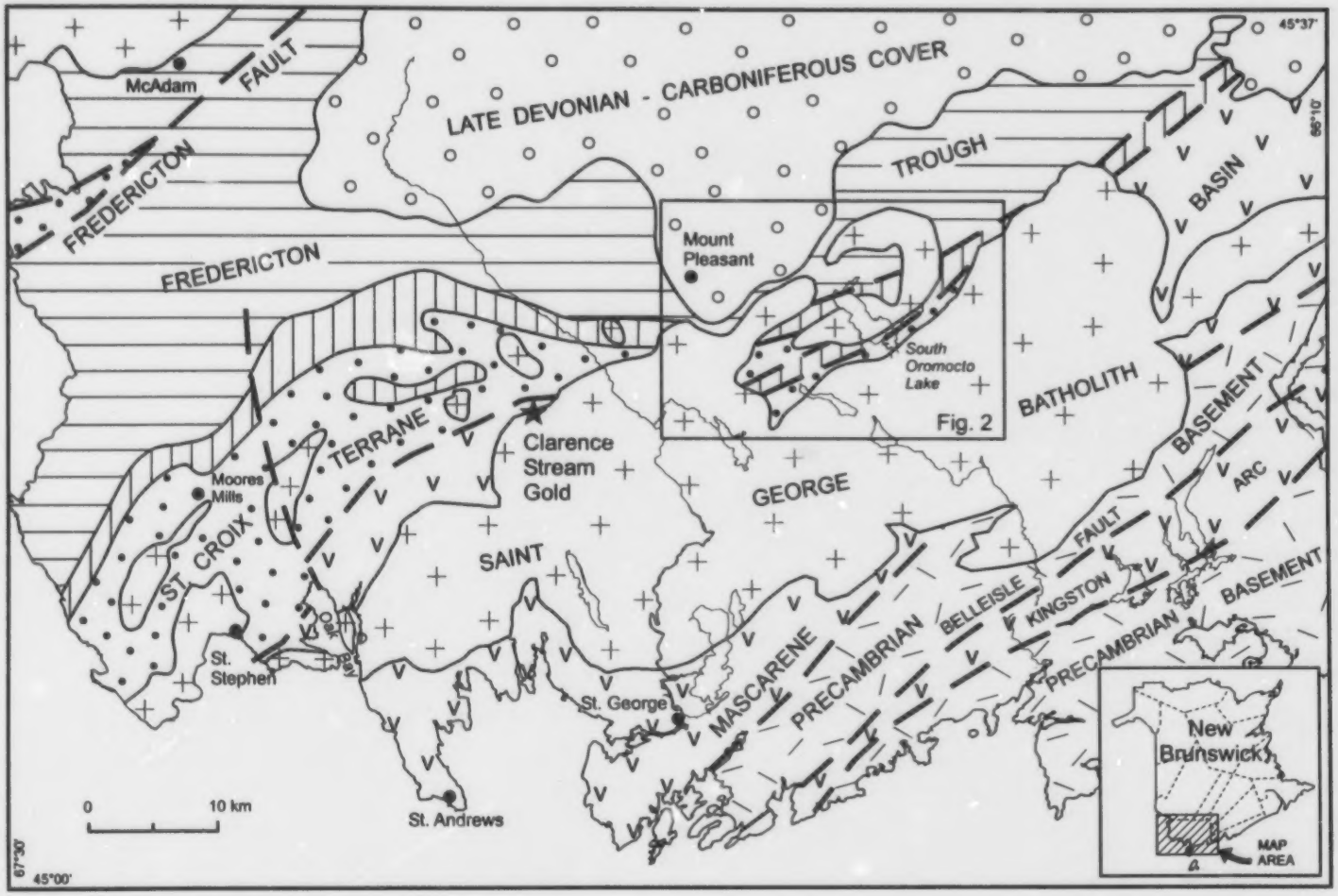

Figure 1. Geotectonic map of southwestern New Brunswick. ▥ – Regional distribution of the Digdeguash Formation within the Fredericton Trough.

Mascarene Basin (Figure 1). As South Oromocto Lake lies only a few kilometres to the east of the Clarence Stream property, a better understanding of the geology in the roof pendant may prove useful to gold exploration in this part of southwestern New Brunswick.

REGIONAL GEOLOGIC SETTING

The Late Silurian to Late Devonian Saint George Batholith was emplaced in a major shear zone separating Ordovician sedimentary rocks of the St. Croix Terrane to the northwest from mainly Precambrian volcanic and plutonic rocks to the southeast (Fyffe and Fricker 1987; McLeod 1990) (Figure 1). The Saint Croix Terrane is underlain by the black shale (Calais Formation), feldspathic wacke (Woodland Formation), and quartz-rich sandstone (Kendall Mountain Formation) of the Cookson Group (Ruitenberg 1967, 1968; Ludman 1987, 1991). The Silurian Fredericton Trough, lying on the northwest flank of the St. Croix Terrane, contains lithic wacke and shale (Digdeguash Formation), feldspathic wacke and maroon mudstone (Sand Brook Formation), and calcareous wacke and shale (Flume Ridge Formation) of the Kingsclear Group ((McKerrow and Ziegler 1971; Ruitenberg 1967, 1968, 1972; Fyffe 1991; McLeod *et al.* 1994).

The Mascarene Basin contains a sequence of Silurian to Early Devonian volcanic and sedimentary rocks that cover the contact zone between the St. Croix Terrane and Precambrian basement (Fyffe *et al.* 1999). Conglomerate of the Oak Bay Formation lies along the northwestern margin of the Mascarene Basin and is probably no older than Early Silurian based on the presence of a pentamerid brachiopod in a limestone clast. Conformably overlying, fine-grained sandstones, siltstones, and volcanic rocks of the Waweig Formation contain brachiopods that suggest a late Early to Late Silurian (late Llandoverian to Pridolian) age (Cumming 1967; Pickerill 1976).

The paleogeographic relationship between the Silurian rocks of the Mascarene Basin and the Fredericton Trough, lying on opposite flanks of the Ordovician St. Croix Terrane (Figure 1), is difficult to ascertain since the ages of the Oak Bay and Waweig formations are only loosely constrained to between the Early and Late Silurian, and no fossils were previously known from the Digdeguash Formation. Alcock (1946) and MacKenzie and Alcock (1960a, 1960b) considered the Oak Bay and Waweig formations of the Mascarene Basin to be entirely younger than strata to the northwest because of the unconformity exposed at Oak Bay. No distinction was made at that time between the rocks of the St. Croix Terrane and Fredericton Trough and all strata to the northwest were included in the Ordovician or older Charlotte Group. More recently, Ruitenberg (1967, 1968) divided the Charlotte Group into the Cookson, Digdeguash, and Flume Ridge formations. He considered the Digdeguash Formation to be a lateral facies equivalent of the Waweig Formation and to be Late Silurian to Early Devonian in age. Fyffe and Miller (1992) argued that the Digdeguash Formation could be as old as Late Ordovician, because underlying quartzite and shale in the Kendall Mountain Formation of the Cookson Group are dated as early Caradocian by graptolites found at Moores Mills (Fyffe and Riva 1990) (Figure 1), and calcareous strata correlated with the overlying Flume Ridge Formation contain a Silurian (Llandoverian–Wenlockian) graptolite fauna along strike in Maine (Osberg 1968). Fyffe *et al.* (1999) contended that the conglomerate of the Oak Bay Formation, and volcanic and volcaniclastic beds that comprise a significant proportion of the Waweig Formation, bear little resemblance in terms of lithology or structural style to the polydeformed, turbiditic sedimentary rocks of the Digdeguash Formation.

STRATIGRAPHY OF THE SOUTH OROMOCTO LAKE AREA

Tupper (1959) included the strata in the South Oromocto Lake roof pendant in the dark and light argillite divisions of the Charlotte Group. As noted above, the Charlotte Group was considered to be entirely Ordovician or older in age since it was unconformably overlain by conglomerate of the Silurian Oak Bay Formation in the Oak Bay area. The dark argillite division outside the roof pendant has since been subdivided into the Ordovician Cookson Group and Silurian Digdeguash Formation, and the light argillite division is now referred to as the Flume Ridge Formation (Ruitenberg 1967, 1968; Ruitenberg and Ludman. 1978; Ludman 1987, 1991). Ruitenberg (1972) and Ruitenberg and Ludman(1978) considered all the strata in the roof pendant to belong to the Silurian Waweig Formation and to be a facies of the Digdeguash Formation. On the other hand, Fyffe and Brown (1996) in their petrographic study of wacke beds in drill core from the South Oromocto Lake area concluded that a direct correlation with the Digdeguash Formation was warranted on the basis of lithological and sedimentological characteristics.

Mapping during the summer of 2000 has shown that the South Oromocto Lake roof pendant contains a variety of hornfelsic sedimentary rocks that have lithological similarities to the Kendall Mountain Formation of the Ordovician Cookson Group, and to the Digdeguash and Sand Brook formations of the Kingsclear Group (Figure 2). The type section of the Sand Brook Formation is located just to the northeast of the roof pendant along Sand Brook; light grey to greyish green, thin- to medium-bedded, fine- to medium-grained, feldspathic wacke and greyish maroon silty mudstone in the northern part of the roof pendant represent the along-strike continuation of those in the type section. Thin- to medium-bedded, fine-grained, light grey quartzite interstratified with medium to dark grey, silty mudstone, characteristic of the Ordovician Kendall Mountain Formation, and medium to dark grey, medium- to coarse-grained, lithic wacke interstratified with medium to dark grey silty mudstone, and minor black carbonaceous shale of the Digdeguash Formation occupy three narrow, fault-bounded belts in the southern part of the roof pendant.

The most northerly of these belts extends northeastward from Highway 785 to Little McDougall Lake and Otter Lake. This belt contains strata of Kendall Mountain Formation in the northwest and Digdeguash Formation in the southeast. The contact between these two units is exposed on a woods road on the west side of Jimmy Hill and appears to be conformable. Grading in thick, lithic wacke beds in outcrop and drill core in the vicinity of Otter Lake indicates that the Digdeguash Formation faces consistently to the southeast away from the quartz-rich sandstones of the Kendall Mountain Formation. The Kendall Mountain Formation is juxtaposed directly against the Sand Brook Formation along the northwestern margin of this belt; therefore, a northeast-trending fault passing through the northern tip of South Oromocto Lake is required to account for the absence of intervening Digdeguash Formation along this contact. The southeastern boundary of this belt is also interpreted as a fault since the Digdeguash Formation faces toward the southeast into psammitic rocks that likely correlate with the older Kendall Mountain Formation (see below).

Medium- to thick-bedded, andalusite–cordierite-bearing, medium grey psammite and dark grey semi-pelite, exposed to the southeast at the McDougall Lake Inlet bridge over Highway 785, are interpreted to belong to the Kendall Mountain Formation based on the presence of rare, thick beds of light grey grit containing 1–2 mm quartz and white feldspar granules. Farther to the southeast on the headwaters of Nason Brook, a sequence of lithic wacke typical of the Digdeguash Formation grades consistently to the southeast and thus appears to represent the younger part of this section as would be expected if the strata along the McDougall Lake Inlet are correctly correlated with the Kendall Mountain Formation.

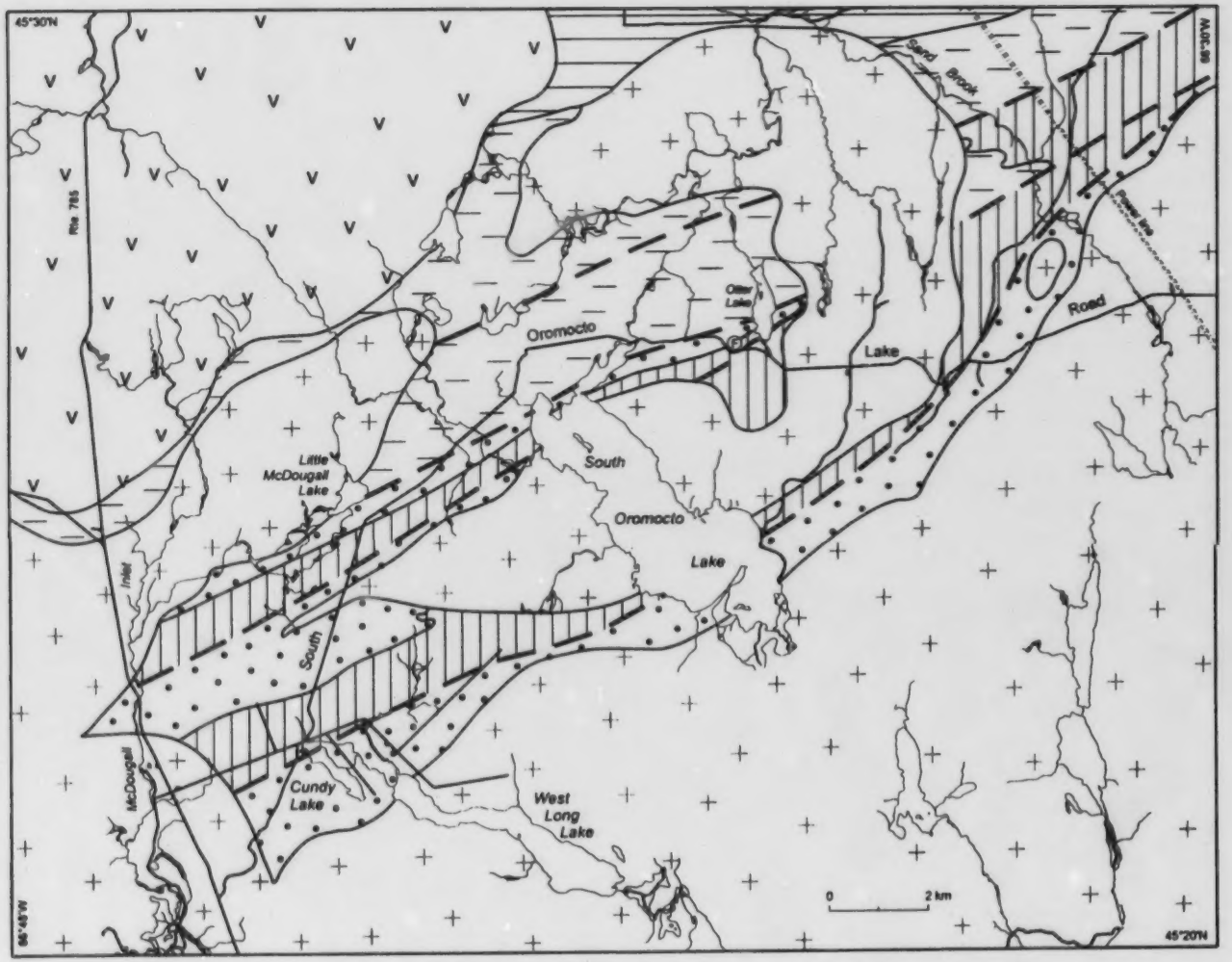

Figure 2. Geology of the South Oromocto Lake area. Symbols: – Kendall Mountain Formation; – Digdeguash Formation; – Sand Brook Formation; – Flume Ridge Formation; – Saint George Batholith and satellite plutons; – Mount Pleasant Caldera. (F) – Fossil site near Otter Lake. Location of map area is shown on Figure 1.

Quartz-rich psammitic rocks correlated with the Kendall Mountain Formation are exposed in the most southerly belt trending along the northern margin of the Saint George Batholith from Cundy Lake northeastward to Three Brooks. The contact to the northwest with the Digdeguash Formation in the Nason Brook area is interpreted as a fault since grading in the latter is toward the southeast.

GRAPTOLITES FROM THE DIGDEGUASH FORMATION

During the recent map survey, graptolites were discovered in the Digdeguash Formation about 1.8 km east of the bridge on the South Oromocto Lake Road over the South Oromocto River. The site is located 200 m up a woods road that branches north off the South Oromocto Lake Road about 900 m west of the camp road into Otter Lake. The graptolites occur in black shale interbedded with lithic wacke striking 65° and dipping 80° to the southeast. The wacke beds grade to the southeast and are no more than 100 m stratigraphically above the contact with quartzite of the Ordovician Kendall Mountain Formation. The following species have been identified:

1. *Coronograptus cyphus* (Lapworth)
2. *"Diplograptus"* aff. *"D." elongatus* Churkin and Carter, or
3. *"Diplograptus"* aff. *"D." tcherskeyi tcherskeyi* Obut and Sobolevskaya
4. *Glyptograptus* sp.
5. *Atavograptus*?, fragments
6. *Normalograptus* spp., thin and thick forms, not better identified.

These Silurian graptolites belong to the *Coronograptus cyphus* Zone of the upper Rhuddanian Stage of the lower Llandovery.

DISCUSSION AND CONCLUSIONS

The discovery of Silurian graptolites in black shale interbedded with wacke in the South Oromocto Lake area during the recent mapping confirms assignment of these rocks to the Digdeguash Formation by Fyffe and Brown (1996). Previous lithological comparison to the relatively shallow-water, shelly-fauna-bearing, volcaniclastic-rich strata of the Waweig Formation by Ruitenberg (1972) is effectively ruled out by the presence of this deep-water fauna. The new paleontological evidence substantiates the regional separation of the dark argillite division of the now abandoned Charlotte Group into the Ordovician Cookson Group and Silurian Digdeguash Formation as proposed by Ruitenberg (1967, 1968). The Digdeguash Formation is shown to be the same age as the Hayes Brook beds underlying the Fredericton Trough in central New Brunswick (Fyffe 1995).

Although it has been shown that the sedimentary rocks in the South Oromocto Lake area are comparable to the Kendall Mountain, Digdeguash, and Sand Brook formations rather than the Waweig Formation, the question remains as to whether the Digdequash and Waweig formations can be considered to represent lateral facies of each other in a regional sense. Fossil evidence suggests that the Waweig Formation is no older than the Telychian Stage of the (upper) Llandoverian Series (Cumming 1967; Pickerill 1976) and, therefore, several graptolite zones younger than the Rhuddanian Digdeguash Formation. It could be argued, however, that the Oak Bay Formation rather than the Waweig Formation represents the shallow-water facies of the Digdeguash Formation. Ruitenberg (1967) mapped a conglomeratic horizon along what he considered to be a faulted contact between the Cookson Group and Digdeguash Formation, and correlated

it with the Oak Bay Formation. Located just north of the Ordovician graptolite site in the Kendall Mountain Formation at Moores Mills, it appears to sit at the base of the Digdeguash Formation, if the presence of the interpreted fault is discounted. It, therefore, may serve to define the boundary between the Ordovician St. Croix Terrane and Silurian Fredericton Trough (Figure 1) and would be no younger than Rhuddanian in age. If this interpretation is correct, then the conglomerate near Moores Mills is older than the conglomerate at the unconformity on Oak Bay.

From the above considerations, uplift and erosion along the boundary between the St. Croix Terrane and Fredericton Trough can be inferred to have taken place between late Caradocian and Ashgillian time, prior to formation of the Mascarene Basin. It would, therefore, seem likely that the Waweig Formation in the Mascarene Basin is the chronostratigraphic equivalent of the Sand Brook Formation, which overlies the Digdeguash Formation in the Fredericton Trough. Conglomeratic wacke horizons at the contact between the Digdeguash Formation and Sand Brook Formation, exposed on Cox Brook to the west of Mount Pleasant (Figure 1), could then represent a distal facies of the Oak Bay Formation deposited on the northwestern margin of the St. Croix Terrane. Transgression of the Oak Bay and Waweig formations onto the southern margin of the Saint Croix Terrane may represent a later Silurian (late Llandoverian?) event related to the development of the Mascarene Basin behind the Early Silurian Kingston volcanic arc (Fyffe *et al.* 1999). The conglomeratic horizon at the base of the Digdeguash Formation near Moores Mills marks the paleogeographic margin of the earlier-formed Fredericton Trough along the northwestern margin of the St. Croix Terrane. Accordingly, Appalachian tectonic events that led to the formation of the Fredericton Trough and the Mascarene Basin are probably not related.

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MAPTOOL: A NEW SOFTWARE PROGRAM FOR MANAGING FIELD DATA†

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MapTool is a program, developed jointly by the New Brunswick Geological Surveys Branch and CARIS, to aid in the digital capture, display, management, and distribution of geological field data. Through a series of simple on-screen forms, geologists can digitally record their field observations into a relational database and associate them with outcrop symbols on a digital geology map. The outcrop symbols are geo-referenced using data retrieved from a handheld global positioning system receiver. By periodically uploading field data through the course of a mapping project, map preparation and interpretation can be expedited significantly. The result is a geological map with an underlying relational database of field observations that can be distributed to users. As MapTool stores its data in Microsoft Access, it can be exported, if necessary, to other popular database formats (e.g., Oracle, dBase), and linked to digital maps in other geographic information system programs. Efforts are underway to create a version of MapTool to run on a handheld computer, which will alleviate the current requirement of transcribing field notes.

MapTool est un programme que la Direction des études géologiques du Nouveau-Brunswick a conjointement mis au point avec CARIS pour faciliter la saisie numérique, l'affichage, la gestion et la distribution des données de terrain géologiques. Les géologues peuvent, grâce à une série de masques simples à l'écran, enregistrer numériquement leurs observations de terrain dans une base de données relationnelle et les associer à des symboles d'affleurements sur une carte géologique numérique. Les symboles d'affleurements sont géocodés à partir de données extraites à l'aide d'un récepteur portatif du système de positionnement global. Le téléchargement périodique des données de terrain au cours de la réalisation d'un projet de cartographie peut substantiellement accélérer la préparation et l'interprétation des cartes. Les intéressés obtiennent une carte reliée à une base de données relationnelle sous-jacente d'observations de terrain pouvant être distribuée aux utilisateurs. Comme MapTool enregistre ses données dans Microsoft Access, on peut exporter celles-ci, au besoin, dans d'autres formats de base de données populaires (p. ex. Oracle, dBase) et les relier aux cartes numériques d'autres programmes de systèmes d'information géographique. On est présentement en train de créer une version de MapTool qui fonctionnera sur un ordinateur portatif, ce qui éliminera l'obligation actuelle de transcrire les observations de terrain.

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† New Brunswick Geological Surveys Branch ordinary budget.

INTRODUCTION

Traditionally, geologists record field observations in a standard notebook at an outcrop. These observations are distilled by the geologist, the basic features are plotted on a base map, and ultimately a geological interpretation is made. Unfortunately, many of the recorded observations are not conveyed on a hard-copy map, nor are they readily obtainable by the users of these maps. Furthermore, these valuable data are commonly unretrievable when the "owner" of the field notes relocates or retires. Hence, subsequent interpretations of the area must rely solely on hard-copy maps, which convey only some of the original observations. Outcrop detail that can be garnered from a map is typically limited to approximate location, group–formation–unit, structural measurements, and, perhaps, type of mineralization. Few maps contain outcrop data relating to such characteristics as coordinate location, intensity and type of alteration and mineralization, specific rock type, development and overprinting relationships of structural fabrics, colour, magnetic characteristics, and bed thicknesses, to name but a few, yet this information was, in all likelihood, recorded by the field mapper. Because these details are unavailable to later mappers, an enormous amount of duplication of effort is required to remap an area. The need to revisit outcrops to gather data that has been observed before is inefficient at best, especially in light of the recent advances in digital data capture and management.

PURPOSE

This paper describes the new MapTool data collection program and how it, in conjunction with a handheld global positioning system (GPS) receiver, is being utilized by field geologists to improve digital geology maps produced by the New Brunswick Department of Natural Resources and Energy.

DATA COLLECTION AND ENTRY

For this version of MapTool, field observations are recorded in the traditional manner using a field notebook. However, the location of the outcrop is not merely plotted on a base map or aerial photo, but is recorded digitally using a handheld Garmin GPS receiver. These devices have proven to be very reliable in the field and are positionally accurate to within 10 m in this Province. A way point number is assigned to each outcrop and stored in the GPS unit with the positional data.

Entering field data into MapTool is a two-stage process. The first stage uses data stored in the GPS receiver to enter the location of an outcrop onto a digital map and assign it a unique alphanumeric identifier (KEY). The second stage necessitates transcribing the observations stored in the geologist's field book into a relational database through a series of thematic on-screen forms. The KEY, which is stored on the map and in the database, is the link between the two.

Stage 1

Outcrop locations are recorded on-site using a Garmin 12(XL) GPS receiver. A 6-digit numeric way point number is entered into the GPS at each outcrop, or at each station along a section of outcrop. The first two digits represent the year (e.g., 01), the last four represent a counter (e.g., 0375). Positional information is recorded as Latitude–Longitude, using a NAD83 datum. A two-letter designation, typically a persons initials, is assigned to each geoscientist using the system (e.g., JP). The way point number preceded by the mapper's initials comprises a unique KEY (e.g., JP010375) for every new geological

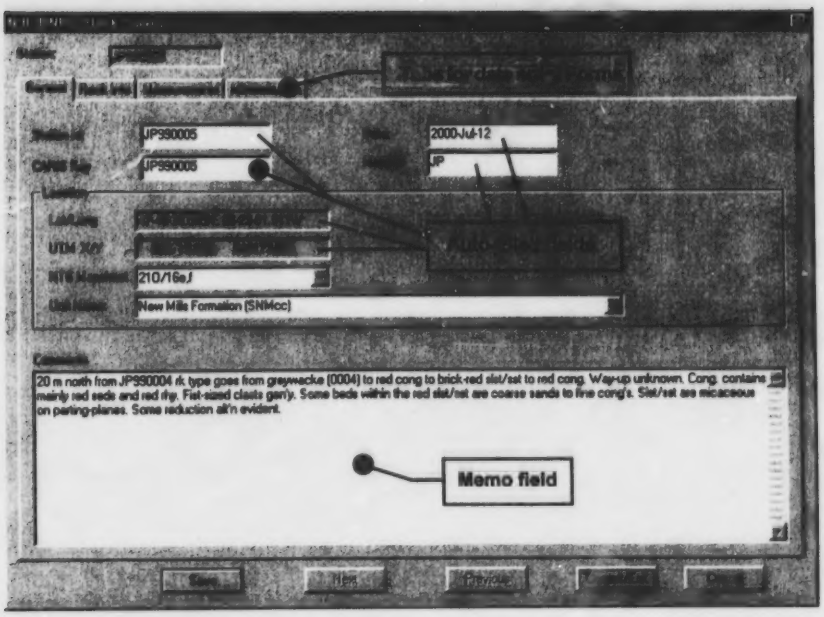

Figure 1. "General" form as it appears after downloading way point data from the Garmin GPS receiver.

information point (GIP) recorded. MapTool interfaces with the Garmin 12 through a serial-port cable. When initiated, the program downloads the positional information from the Garmin to the database. Concurrently, it will plot outcrop symbols onto an on-screen map, prefix the way point numbers with the users' assigned initials, and attach these KEYS to the outcrop symbols. Additional information such as date, X–Y coordinates (New Brunswick Stereographic), and mappers' initials are added automatically by the system. A view of the populated fields after Stage 1 is completed is shown in Figure 1.

Stage 2

The second stage of the process requires using on-screen forms, similar to Figure 1, to populate the database. To make this process efficient, most data-entry boxes have drop-down picklists from which items can be selected (Figure 2). The picklists comprise simple glossaries stored as text files in a subdirectory of MapTool, that can be easily customized by the user with any Windows text editor. Picklists may be single- (e.g., rock name) or multi-pick (e.g., primary features) to allow for full descriptions. Multiple rock types within a single outcrop are described individually and assigned a volume % of the exposure. Data from past projects can also be compiled providing the digital outcrop symbols are assigned a KEY and given the correct attributes for recognition by the MapTool software.

THE USER INTERFACE

Four forms are present for data entry: "General," "Rock Info," "Measurements," and "Mineralization." In general, the forms should be filled in from top to bottom. Within the forms there are five types of fields:

1. Radio-button fields (Figure 3). These are arranged in sets where a selection is mandatory. For example, you must choose one of "Igneous", "Sedimentary", or "Metamorphic" on the Rock Info

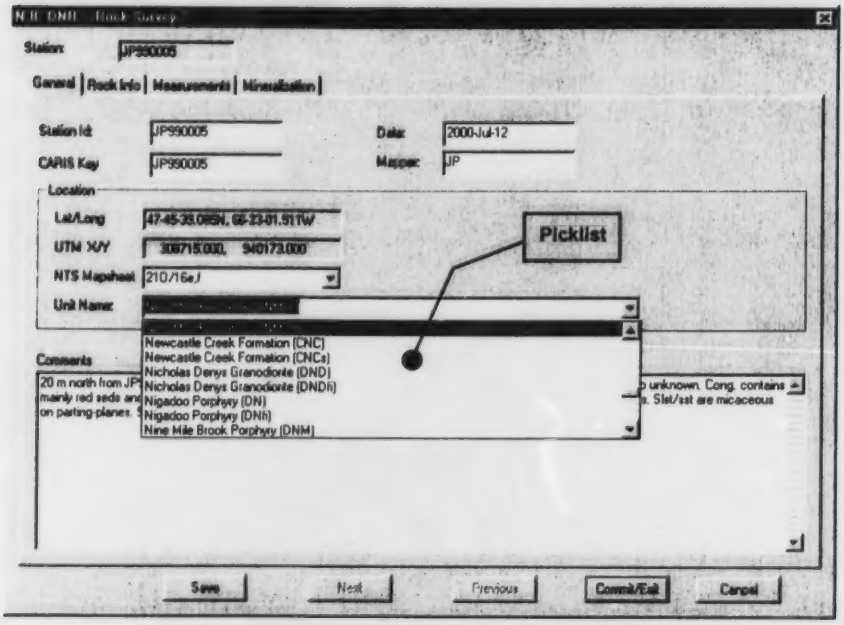

Figure 2. "General" form showing drop-down picklist of Provincial bedrock units.

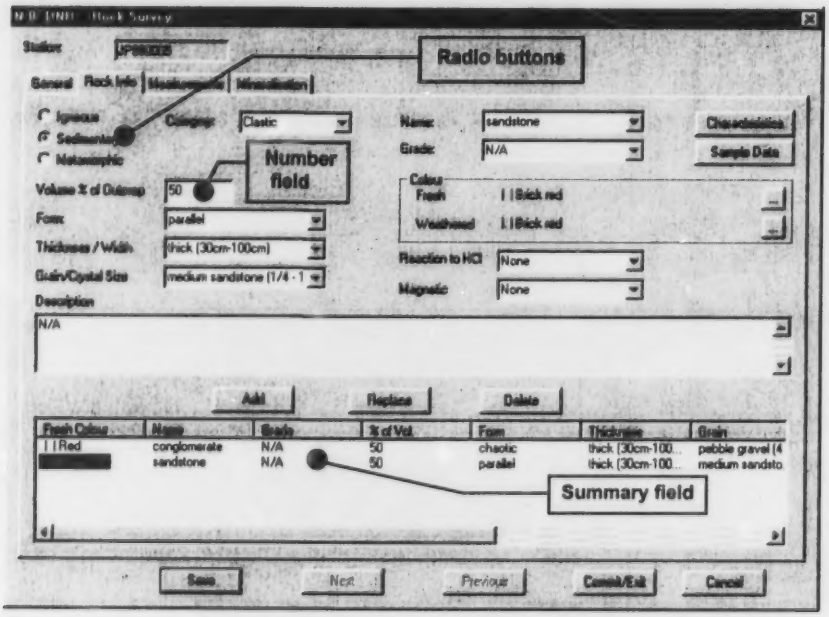

Figure 3. The "Rock Info" form showing positions of Radio Buttons, and the Number and Summary fields.

form. Radio-button selections are linked to sets of applicable picklists, i.e., a picklist of sedimentary rocks will appear in the "Name" field if the "Sedimentary" radio-button is selected.

2. On-off buttons (Figure 4). Similar in appearance to radio-buttons but selection is not mandatory.

3. Picklist fields (see Figure 2). Clicking on the black arrow at the right of these fields will generate a drop-down picklist. These fields may be single- or multi-pick.

4. Memo fields for entering descriptive notes or general comments (see Figures 1 and 3).

5. Number fields, of which there are 3 on the forms. Two are for entering the volume % of outcrop and mineralization on the "Rock Info" and "Mineralization" forms respectively, the other is for entering the attitude (e.g., strike/dip) of fabric elements on the "Measurements" form (see Figures 3 and 4).

General

In addition to the fields populated automatically by MapTool, the General form (see Figure 1) has fields for NTS Map sheet, Unit Name (Formation), and a memo field for general outcrop description. The lists for "NTS Mapsheet" and "Unit Name" (see Figure 2) are Provincial in scope, so the program can be applied to any part of New Brunswick.

Rock Info

The Rock Info form (Figure 3) has fields for rock name, form, grain/crystal size, bed thickness/width, colour, sample description, and magnetic character, among others, and embedded subforms for "Colour," "Characteristics," and "Sample Data." There are separate colour buttons for "Fresh" and "Weathered" that spawn the same sub-form. Users can opt for the GSA Colour Scheme designation (e.g., 5 G 8/1; light greenish grey) or use "Intensity" (e.g., Light), "Modifier" (e.g., Greenish), and "Colour" (e.g., Grey) to describe the rock. The "Characteristics" subform contains picklists for "Texture"(e.g., porphyritic, amygdaloidal), "Modifiers" (e.g., crystal-lithic, polymictic), "Primary Features" (e.g., graded bedding, flow banding), and "Alteration," which includes picklists for "Type" and "Intensity." The "Sample Data" subform has a radio-button for selecting "Rock Sample" or "Photograph." A picklist for "Reason for Sample" (e.g., thin section, lithochemistry) is available for the "Rock Sample" selection. Once the type of sample is defined, MapTool automatically assigns a unique identity code based on the station number (KEY) of the outcrop and a unique extension. The identity codes are automatically incremented for multiple photograph or sample types at the same station. The system will also differentiate between samples of different rock type taken at the same station. For example, hand samples of a host rock and a dyke would have extensions R1HS1 (rock 1, hand sample 1) and R2HS1 (rock 2, hand sample 1) respectively. Photographs have extensions R*x*PH*y*, where *x* and *y* denote rock number and photograph number respectively.

Measurements

The Measurements form (see Figure 4) allows users to enter data pertaining to primary and secondary fabric elements in the outcrop. These include designation (e.g., S1, F2), type (e.g., bedding, cleavage),

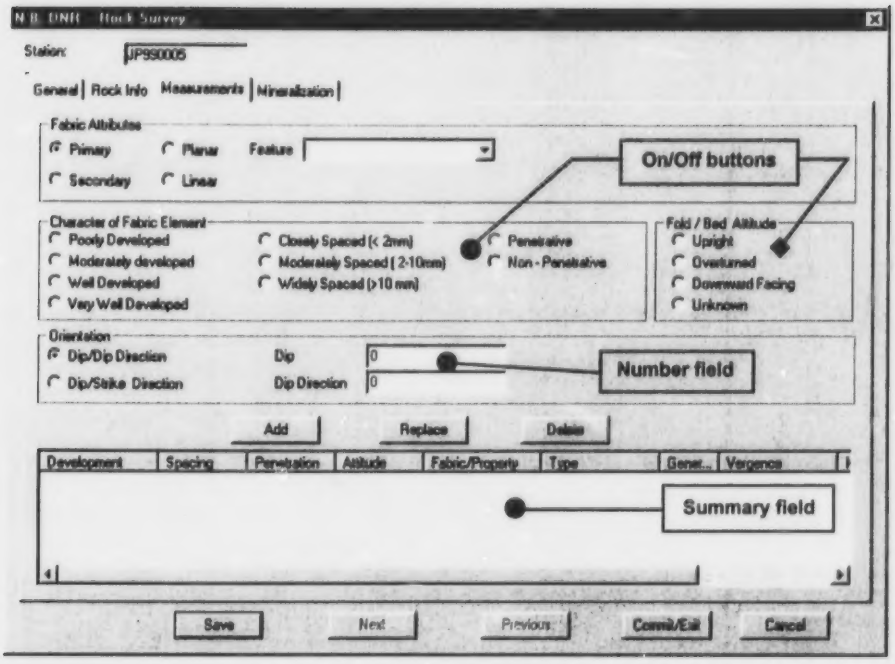

Figure 4. The "Measurements" form showing On/Off buttons, and the Number and Summary fields.

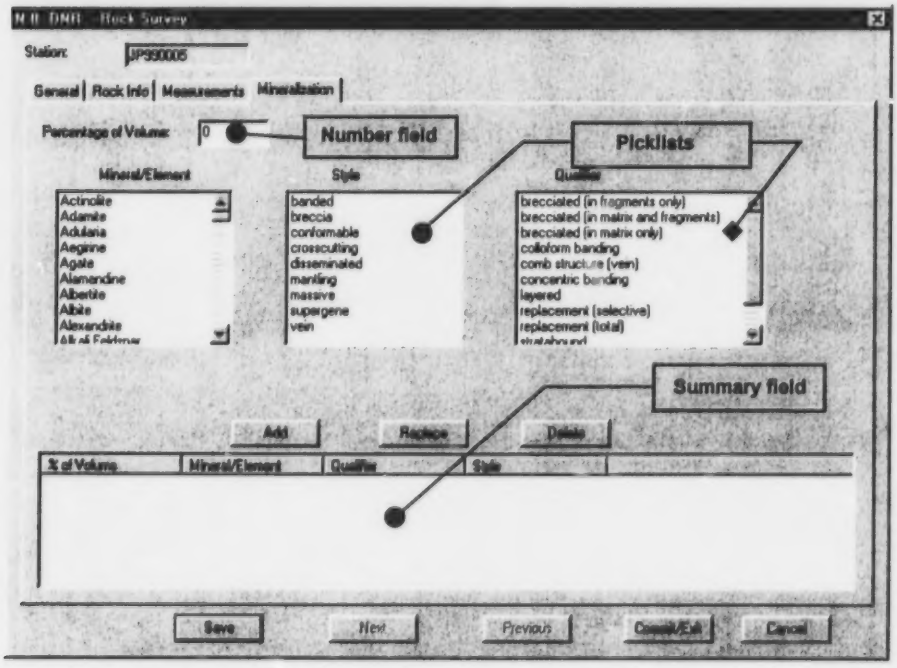

Figure 5. The "Mineralization" form showing the positions of the Number, Picklist, and Summary fields.

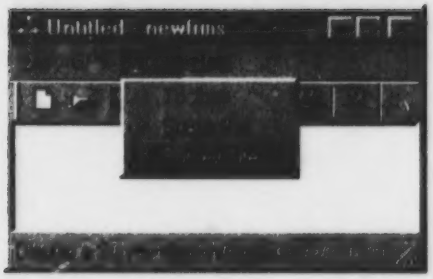

Figure 6. Menu bar for MapTool showing the drop-down "View" menu.

vergence, orientation, and characteristics. Both standard formats for recording orientation, i.e., dip/dip and strike/dip, are supported.

Mineralization

The Mineralization form (see Figure 5) has picklists for type, amount (%), and style of mineralization as well as a list of modifiers (e.g., layered, stratabound).

Once the appropriate fields have been populated, the user selects the "Add" button to temporarily commit the data to the database. A summary of this data set will then appear at the bottom of the form in an uneditable (system) field (see Figures 3, 4, 5). Additional entries appear on separate lines. For example, each structural measurement and its accompanying characteristics have to be "Add"ed separately and will therefore appear on separate line in the summary field. Modifications to database entries that have been added can be made by highlighting the first item on the summary line. This will repopulate the fields with the original entries, that can then be changed. The summary field is updated by choosing the "Replace" button. Once data entry for a station is complete, the user activates the "Save" and "Commit/Exit" buttons to populate the MapTool database. The process is repeated by selecting "Survey Site" from the "View" menu on the MapTool menu bar (Figure 6).

Once all the field data have been entered into MapTool, its function is over; however, the database itself can be queried and analysed with any suitable software program. Furthermore, most popular GIS programs can utilize ODBC (Open Database Connectivity), a widely accepted interface between programs and databases, to link a digital map to the MapTool database, which is ODBC compliant. The database can then be queried and the results displayed on a map.

DEVELOPMENT

The MapTool program has been, and will be, modified in response to feedback from users. The immediate goal is to develop a PDA (Personal Data Assistant)-based version of MapTool. This will allow on-site input of field observations, eliminating the duplication of effort currently required to transcribe field notes into digital format—a process that is inherently error-prone. Data from the PDA can be periodically downloaded into the user's desktop or laptop version of the MapTool database. An added feature of the PDA-version would be the capability to record on-screen sketches and form-surface maps. PDAs are

smaller than a field book (13 x 8 x 1.5 cm; 5 x 3 x 0.5 in.), weigh between 170 and 255 g (6 and 9 oz.), and can be shock- and splash-proofed with a number of accessory products.

DISCUSSION

Improved accuracy and precision of handheld GPS receivers and advances in digital data storage devices (capacity and processing power) have helped to transform how geological data is being recorded, spatially referenced, managed, and distributed. Ultimately, all data will be recorded digitally in the field using available hardware. Most high-end digital cameras can record voice messages and short video clips as well as still pictures; handheld (pocket) personal computers utilize handwriting-recognition software, can be used as sketch pads and dictation devices, and can outperform a Pentium I desktop computer; and GPS receivers provide extremely accurate positional data. Furthermore, all these devices can be fortified for use in the field and data from these devices can be downloaded and backed up periodically so there is less chance for data loss.

The advantages of using computer hardware, like the devices mentioned above, in conjunction with computer programs like MapTool, are clear:

1. They allow quick entry of on-site field observations.
2. Analysis of data is simplified because of its digital format.
3. The MapTool interface insulates users from the nuts and bolts of database operations.
4. All field observations are available for users, not just those gleaned from analog maps.
5. The integration and interpretation of multiple data sets, from which we infer geological models and targets, is enhanced.

ACKNOWLEDGEMENTS

The MapTool program was written by Peter Benton, who continues to make himself available when called upon to make modifications. Rob van de Poll is thanked for his efforts and initiative in the development process. This manuscript was critically reviewed by Steve McCutcheon, who is also thanked for his comments and suggestions.

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THE GEOLOGICAL SETTINGS OF MASSIVE SULPHIDE DEPOSITS IN THE BATHURST MINING CAMP: A SYNTHESIS †

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The 45 known massive sulphide deposits of the Bathurst Mining Camp occupy more than one stratigraphic position within the volcanic pile; 31 of them are in the Ordovician Tetagouche Group; 13 are in the more-or-less coeval California Lake Group, and one is in the lower part of the Sheephouse Brook Group. Most of these deposits are associated with the first volcanic cycle, which is dominated by quartz–feldspar crystal tuffs of the Nepisiguit Falls Formation in the Tetagouche Group, and feldspar-phyric tuffs and lavas of the Mount Brittain and Spruce Lake formations in the California Lake Group. Eight of them are in second-cycle felsic volcanic rocks of the Flat Landing Brook Formation, also part of the Tetagouche Group.

Deposits in the Nepisiguit Falls Formation are all stratiform proximal type; they are mostly within chloritic mudrocks that are at or near the top of the volcanic pile, the so-called "Brunswick Horizon,"and are associated with oxide iron formation. However, at least one, the Heath Steele deposit, sits beneath quartz–feldspar porphyry and is in the lower part of this formation.

Both stratiform proximal and stratabound replacive deposits occur in the Flat Landing Brook Formation. The former type, e.g. the Stratmat S1 deposit, is hosted by "cherty tuff" that appears to be relatively low in the pile, whereas the latter type (e.g., the Louvicourt deposit) is within fragmental felsic rocks that can occur anywhere in the pile.

Deposits in the Spruce Lake Formation occur in three stratigraphic positions. Deposits such as Caribou are stratiform proximal type and hosted by dark grey shales at or near the bottom of the formation. Deposits like Armstrong A are stratabound replacive type and occur within the felsic volcanic pile, whereas those like Orvan Brook are stratiform distal type and hosted by fine-grained clastic rocks that overlie the volcanic pile. Deposits in the Mount Brittain Formation also occur at the base of and within the felsic volcanic pile. Regardless of host formation, the largest deposits in the California Lake Group are at or near the base of the group.

Les 45 gîtes de sulfures massifs reconnus du Camp minier de Bathurst occupent plus d'une position stratigraphique à l'intérieur de la structure volcanique: 31 d'entre eux font partie du groupe ordovicien de Tetagouche; 13 se trouvent dans le groupe plus ou moins contemporain du lac California et l'un est situé dans la partie inférieure du groupe du ruisseau Sheephouse. La majorité de ces gîtes sont associés au premier cycle volcanique, parmi lequel prédominent des tufs cristallins quartzo-feldspathiques de la Formation de Nepisiguit Falls dans le groupe de Tetagouche ainsi

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† New Brunswick Geological Surveys Branch ordinary budget.

que des laves et des tufs feldspatho-porphyriques des formations de Mount Brittain et de Spruce Lake dans le groupe du lac California. Huit des gîtes se trouvent dans des roches volcanofelsiques de deuxième cycle de la Formation de Flat Landing Brook, qui fait elle aussi partie du groupe de Tetagouche.

Les gîtes de la Formation de Nepisiguit Falls sont tous de type proximal stratiforme; ils se trouvent principalement à l'intérieur de mudstones chloriteux situés au sommet ou près du sommet de la structure volcanique, soit ce qu'il est convenu d'appeler «l'horizon Brunswick», et ils sont associés à une formation de fer oxydé. Au moins un gîte, toutefois, le gîte Heath Steele, se trouve au-dessous de porphyre quartzo-feldspathique dans la partie inférieure de cette formation.

Des gîtes proximaux stratiformes et des gîtes de substitution stratoïdes sont présents dans la Formation de Flat Landing Brook. Le premier type de gîtes, p.ex. le gîte Stratmat S1, sont inclus dans un «tuf cherteux» qui semble placé à un niveau relativement bas dans la structure, tandis que les gîtes du second type, p. ex. le gîte Louvicourt, se trouvent à l'intérieur de roches felsiques détritiques pouvant être présentes n'importe où à l'intérieur de la structure.

Les gîtes de la Formation de Spruce Lake sont présents dans trois positions stratigraphiques. Les gîtes comme le gîte Caribou sont des gîtes de type proximal stratiforme encaissés dans des schistes gris foncé au fond de la formation ou près de celui-ci. Les gîtes comme le gîte Armstrong A sont des gîtes de substitution stratoïdes présents à l'intérieur de la structure volcanofelsique, tandis que les gîtes comme celui du ruisseau Orvan sont des gîtes distaux stratiformes qui sont inclus dans des roches clastiques à grain fin recouvrant la structure volcanique.Les gîtes de la Formation de Mount Brittain sont eux aussi présents à la base ainsi qu'à l'intérieur de la structure volcanofelsique. Peu importe la formation hôte, les gîtes les plus étendus dans le groupe du lac California se trouvent à la base ou près de la base du groupe.

INTRODUCTION

The Bathurst Mining Camp hosts at least 45 volcanogenic massive sulphide deposits, including the giant Brunswick No.12 mine. Since 1964 when production started until the end of 2000, this mine has produced 95 679 000 t of ore grading 8.81% Zn, 3.49% Pb, 0.35% Cu and 101.0 g/t Ag (P. Bernard, written communication, 2001). This deposit lies at the top of first-cycle felsic volcanic rocks in the lower part of the Ordovician Tetagouche Group. However, the stratigraphic settings of many of the other deposits in the camp were not clear until recently, as a result of work carried out under the EXTECH II Project (1993–1998). Now, three groups that are more or less coeval have been formally defined based upon new high-resolution airborne geophysics, 1:20 000 scale geological mapping, and U–Pb radiometric dating. They are the California Lake, Sheephouse Brook and Tetagouche groups. These three groups host all the major deposits in the Bathurst Mining Camp (Figure 1).

The purpose of this paper is to show the position of the 45 known deposits (Table 1) within this newly recognized stratigraphy. This is done with reference to representative drill cores from deposits in each group. We also classify them with respect to their mode of emplacement and summarize the main characteristics of each type.

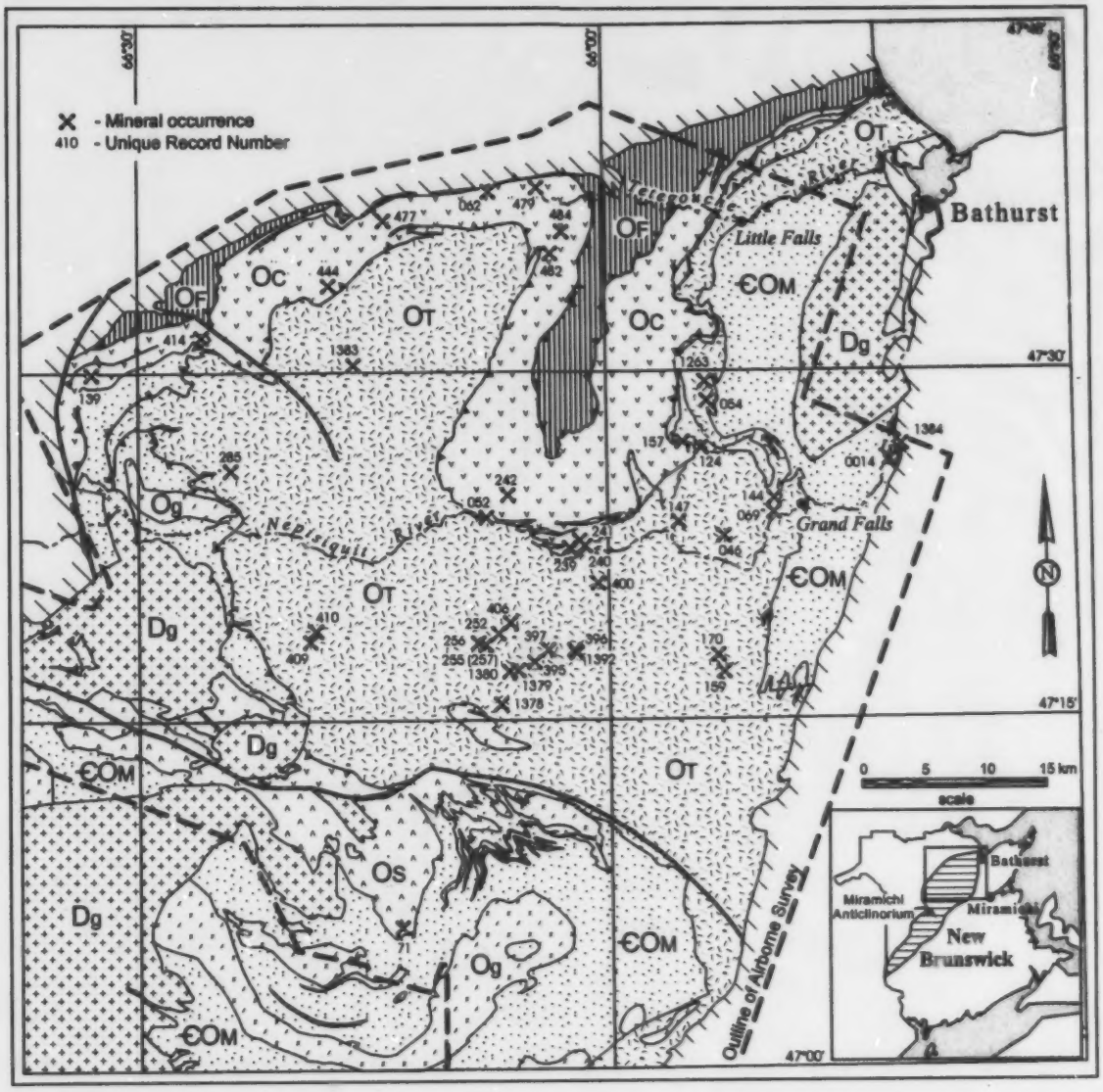

Figure 1. Simplified geology of the Bathurst Mining Camp showing the locations of the known mineral deposits. Rock units as follows: €OM – Miramichi Group; OC– California Lake Group; OF – Fournier Group; OS – Sheephouse Brook Group; OT – Tetagouche Group; Og – Ordovician granitoid rocks; Dg – Devonian granitoid rocks. Unique Record Numbers are from the New Brunswick Mineral Occurrence Database. See Table 1 for deposit names associated with the URN numbers.

Table 1. List of Known Mineral

URN	Deposit	Discoverer	Year	Method	Type	Host	Tonnage	Pb–Zn Pb(%)	Pb–Zn Zn(%)
0484	Armstrong A	Anaconda	1956	EM	BM	SL	3 377 000	0.42	2.26
0482	Armstrong B	Anaconda	1956	EM	BS	SL	---	---	---
0069	Austin Brook	Boylen Group	1952	Geol	BM	NF	234 600	3.67	5.68
0054	Brunswick No. 12	Boylen Group	1953	Mag, EM	BM	NF	46 255 400	4.17	10.29
0144	Brunswick No. 6	Boylen Group	1952	Mag, EM	BM	NF	858 600	3.01	8.08
1263	Brunswick North End	Brunswick M & S	1989	Geol	BM	NF	1 011 000	3.00	6.22
1383	Camel Back	Noranda	1996	AEM, Mag	BM	NF	4 300 000	3.94	8.95
0242	Canoe Landing Lake	Baie Holdings	1960	Soil, EM	SD	CL	3 456 800	0.65	2.48
0159	Captain	Captain Mines	1956	EM	BS	NF	---	---	---
0444	Caribou	Anaconda	1955	Geol, Pros	BM	SL	4 621 000	3.22	6.77
0071	Chester	Chesterville Mines	1955	AEM	BS	CW	1 019 400	1.58	3.95
0170	CNE	Sabina	1978	Silt, IP	BM	NF	236 800	2.74	7.64
0285	Devils Elbow	American Metal Co.	1957	AEM	BS	NF	---	---	---
0046	Flat Landing Brook	Sabina	1975	AEM	BM	NF	1 270 100	1.29	5.62
0409	Halfmile Lake	Texas Gulf/Conwest	1955	Geol, EM	BM	NF	8 528 200	2.83	8.94
0410	Halfmile Lake North	Sweet Grass Oils	1955	EM	BM	NF	1 179 000	0.85	4.51
0124	Headway	K. McDonough	1957	Pros	BM	FL	263 100	2.10	6.16
0395	Heath Steele ACD Zones	American Metal Co.	1954	AEM	BM	NF	553 100	4.18	11.26
0396	Heath Steele B Zone	American Metal Co.	1954	AEM	BM	NF	1 439 500	2.38	5.99
1392	Heath Steele B-5 Zone	Heath Steele Mines	1965	IP	BM	NF	10 100 000	1.80	10.59
0395	Heath Steele C-North	Heath Steele Mines	1981	Mag, EM	BM	NF	2 700 000	2.04	6.03
0397	Heath Steele E Zone	American Metal Co.	1954	AEM	BS	NF	917 000	2.39	5.79
1378	Heath Steele H2 Zone	Noranda	1987	Soil, EM	BM	NF	5 600 000	4.74	12.28
1379	Heath Steele HC-4	Noranda	1991	Geol	BM	NF	8 000 000	3.17	10.15
0257	Heath Steele N-5	Heath Steele Mines	1964	IP	BM	NF	---	---	---
1380	Heath Steele West Grid	Heath Steele Mines	1966	IP	BM	NF	961 500	3.12	7.01
0014	Key Anacon	New Larder U	1953	AM, EM	BM	NF	1 865 400	2.63	6.93
1384	Key Anacon East	Rio Algom	1993	Geol, EM	BM	NF	19 900 000	3.58	7.86
0147	Louvicourt	L. Gray *et al.*	1964	Pros	BM	FL	136 000	1.23	1.00
0477	McMaster	Anaconda	1957	EM	BM	SL	---	---	---
0414	Murray Brook	Kennco	1956	Silt, EM	BM	MB	4 640 000	1.80	4.73
0241	Nepisguit "A"	Kennco	1956	EM	BM	SL	1 542 100	0.60	2.80
0240	Nepisguit "B"	Kennco	1956	EM	BM	SL	1 360 700	0.40	1.90
0239	Nepisiguit "C"	Kennco	1956	EM	BM	SL	635 000	0.70	2.10
0062	Orvan Brook	Tetagouche Exp. Co.	1938	Pros	BM	SL	2 687 200	1.73	5.95
0157	Pabineau	Quebec Smelting & Ref.	1953	EM, Geol	BS	NF	136 000	0.87	2.65
0139	Restigouche	New Jersey Zinc	1958	Soil	BS	MB	302 900	5.27	6.56
0479	Rocky Turn	Anaconda	1957	Pros	BS	SL	131 000	2.69	8.43
0255	Stratmat Boundary	Cominco	1961	Soil, EM	BM	FL	154 000	4.06	10.50
0252	Stratmat Central	Cominco	1972	IP	BM	FL	650 000	3.59	8.52
0406	Stratmat Main	Strategic Metals	1956	EM	BM	FL	1 010 000	2.23	5.35
0252	Stratmat S-1	Noranda	1988	Geol, EM	BM	FL	4 938 000	2.82	6.74
0256	Stratmat West Stringer	Cominco	1972	IP	BS	FL	---	---	---
0400	Taylor Brook (Cons. Mor.)	Consolidated Morrison	1977	AEM	BM	FL	399 100	2.00	4.00
0052	Wedge	Cominco	1956	Geol, Pros	BM	SL	545 200	1.71	5.21
							100 014 700	**3.07**	**7.90**

Notes: Compiled by W.M. Luff (May 1999). Table does not include production. Five deposits do not have calculated estimates but all are < 1 000 000 t for a total of about 2 000 000 t. **URN** – Unique Record Number; **Method**: AM – airborne magnetic, AEM – airborne electromagnetic, EM – electromagnetic, Geol – geology, IP – induced polarization, Mag – magnetic, Pros – prospecting, Silt – silt geochemistry, Soil – soil geochemistry; **Type**: BM – stratiform bimodal volcanic- or sediment-

Deposits in the Bathurst Mining Camp

Resource-----		-----Cu Resource---		Py/Po	Total		
Cu(%)	Ag(g/t)	Tonnage	Cu(%)	Tonnage	Tonnage	Date	Source
0.29	25	---	---	---	3 377 000	1972	Cavalero
---	---	537 400	0.67	---	537 400	1973	Buzas
0.09	82	---	---	3 022 000	3 256 600	1991	Brunswick, Luff,1995
0.34	113	25 000 000	1.10	50 000 000	121 255 400	1997	Brunswick, Luff,1995
0.17	90	1 752 000	1.06	5 000 000	7 610 600	1991	Luff,1995
0.24	110	---	---	---	1 011 000	1992	Luff,1995
0.08	42	---	---	---	---	1999	Discovery hole 96-6
0.65	44	---	---	17 225 100	20 681 900	1995	DNRE Assessment Report 474581
---	---	178 800	2.10	---	178 800	1997	Stratabound Annual Report
---	98	216 300	3.82	60 250 000	65 087 300	1998	Breakwater
0.67	12	6 400 000	1.22	8 300 000	15 719 400	1991	Noranda, Irrinki
---	89	30 800	1.30	---	267 600	1997	Stratabound Annual Report
---	---	362 900	1.20	---	362 900	1965	DNRE Information Circular 84-1
0.03	23	---	---	---	1 270 100	1982	DNRE Information Circular 83-2
0.10	39	---	---	---	8 528 200	1998	Noranda
0.47	9	---	---	---	1 179 000	1994	Noranda
1.43	21	---	---	---	263 100	1966	DNRE Assessment Report 472314
0.29	111	113 900	3.56	3 000 000	3 667 000	1998	Heath Steele Mines
1.69	101	597 400	3.18	50 000 000	52 036 900	1998	Heath Steele Mines
0.51	57	---	---	---	---	1965	Best intersection: hole S-684
0.39	81	---	---	---	2 700 000	1991	Noranda
1.47	102	---	---	1 000 000	1 917 000	1990	Heath Steele Mines
0.88	154	---	---	---	---	1987	Best intersection: hole S-683
0.14	88	---	---	---	---	1991	Best intersection: hole S-1164
---	---	---	---	---	---	1991	Mined out
0.14	87	---	---	---	961 500	1991	Noranda
0.16	84	86 900	1.45	---	1 952 300	1992	Irriniki
0.33	78	---	---	---	---	1993	Discovery hole 93-42
0.42	91	---	---	---	136 000	1976	DNRE Assessment Report 471255
---	---	250 000	0.75	---	250 000	1972	Cavalero
0.22	64	3 590 000	1.88	11 970 000	20 200 000	1999	NovaGold
0.40	10	---	---	---	1 542 100	1976	Williams
0.10	10	---	---	---	1 360 700	1976	Williams
0.40	21	---	---	---	635 000	1976	Williams
0.37	72	---	---	---	2 687 200	1997	Noranda
---	---	---	---	---	136 000	1980	DNRE Assessment Report 472530
---	72	---	---	---	302 900	1998	Breakwater
0.28	101	---	---	---	131 000	1972	Cavalero
0.64	37	---	---	---	154 000	1991	Heath Steele Mines
0.53	50	---	---	---	650 000	1991	Noranda
0.71	60	---	---	---	1 010 000	1991	Noranda
0.44	50	---	---	---	4 938 000	1991	Noranda
---	---	181 000	2.00	---	181 000	1981	DNRE Open File Report 82-31
---	69	---	---	---	399 100	1997	Stratabound Annual Report
1.75	---	---	---	---	545 200	1991	Noranda
0.35	**82**	**39 297 400**	**1.25**	**209 767 100**	**349 079 200**		

hosted massive sulphides, BS – stratabound bimodal volcanic- or sediment-hosted disseminated and stringer sulphides, SD – stratiform sediment-hosted sulphides; **Host**: CL – Canoe Landing Lake Formation, CW – Clearwater Stream Formation, FL – Flat Landing Brook Formation, MB – Mount Brittain Formation, NF – Nepisiguit Falls Formation, SL – Spruce Lake Formation; **Date** – Year calculation was done.

HISTORICAL BACKGROUND

Although it was not recognized as a volcanic-hosted massive sulphide at the time, the first description of a Bathurst Mining Camp deposit was made by Young (1911). He interpreted the "Nipisiguit Iron Ore Deposit," now called Austin Brook (Figure 1), as a replacement body in post-Ordovician "quartz porphyry." He thought this porphyry was of probable tuffaceous origin, and noted that the footwall of the deposit "is very heavily charged with pyrite." Skinner and McAlary (1952) included the volcanic host rocks with the Austin Brook deposit in their Middle Ordovician "Tetagouche group." Subsequently, Smith (1957) assigned most of the rocks in the camp to this group and subdivided it into five informal units. In ascending stratigraphic order, they are as follows: siliceous metasedimentary rocks, acid to intermediate lava and tuff, quartz–feldspar porphyry, basic volcanic rocks and argillaceous sedimentary rocks.

McAllister (1960) summarized the characteristics of the 22 known massive sulphide deposits in the Bathurst Mining Camp at that time, which he subdivided mineralogically into "massive pyrite" and "pyrrhotite and chalcopyrite" types. He noted that all deposits are associated with quartz- and/or feldspar-augen schists of tuffaceous origin; most are in chloritic host rocks, and many are accompanied by iron formation. In fact, he considered the massive sulphides to be a facies of iron formation and described several varieties, including "iron rich red shales," "magnetite iron formation," and "silicate (chlorite) facies." Like Holyk (1957) and Stanton (1959) before him, McAllister reported that the deposits are conformable with "sedimentary horizons." However, it was not clear if all the deposits formed in the same stratigraphic time interval or if they occupy several stratigraphic intervals within the felsic volcanic pile.

Twenty years later, it was still not known whether the deposits occupied one stratigraphic zone (horizon) repeated by folding, or if there are two or more zones (Davies and McAllister 1980). Helmstaedt (1973) reported that the deposits are concentrated in the porphyries near the upper boundary of the basal sedimentary unit of the Tetagouche Group. However, many deposits do not fit this model, e.g., Brunswick 12 (Rutledge 1972; Luff 1977), Key Anacon (Saif *et al.* 1978) and Canoe Landing Lake (Jambor 1979). Subsequently, Franklin *et al.* (1981) divided the deposits into two spatial groups, with each group characterized by a different stratigraphic sequence. Also, the discovery of new fossil localities helped clarify the stratigraphic relationship of the volcanic pile to the underlying sedimentary rocks (cf. Neuman 1984). More recently, van Staal *et al.* (1992) suggested that massive sulphide deposits occur in three stratigraphic positions and McCutcheon *et al.* (1993) reported four.

Much of the previous uncertainty about the stratigraphic distribution of sulphide deposits in the Bathurst Mining Camp, stemmed from a poor understanding of the internal stratigraphy and structure of the Tetagouche Group. For example, it was not until the late1980s that the tectonic significance of high strain zones was recognized and the first formal subdivision of the group was made (cf. van Staal 1987; van Staal *et al.* 1990 and references therein). Many of the stratigraphic subdivisions were first mentioned in the literature by van Staal and Langton (1990) but they were more fully described by van Staal and Fyffe (1991) and McCutcheon *et al.* (1993). The lower "siliceous metasedimentary rocks" were assigned to the newly defined Miramichi Group and many of the "basic volcanic rocks" and some of the "argillaceous sedimentary rocks" were assigned to the Fournier Group, first introduced by Young (1911). The remaining Tetagouche rocks in the camp were divided into six new formations, namely: Vallée Lourdes, Patrick Brook, Nepisiguit Falls, Flat Landing Brook, Canoe Landing Lake and Boucher Brook formations, and were thought to be more or less in ascending stratigraphic order. As a result of work carried out under the EXTECH II Project, the Tetagouche Group of van Staal and Fyffe (1991) has been further subdivided (see Thomas *et al.* 2000; van Staal *et al.*, in press).

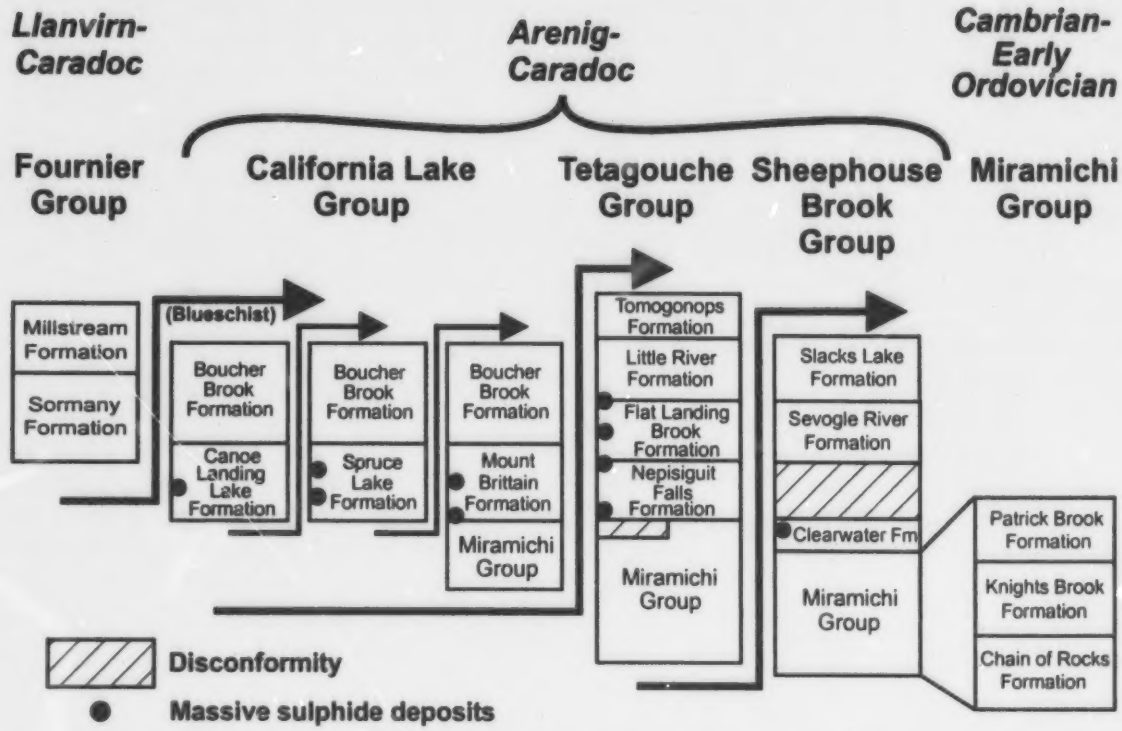

Figure 2. Schematic tectonostratigraphy of the Bathurst Mining Camp showing the relationships among the various groups and the approximate positions of massive sulphide deposits. From left to right in this diagram corresponds more or less to a north to south direction in the camp.

TECTONIC SETTING

The regional tectonic setting of the Bathurst Mining Camp has been described by van Staal (1994) and so is not discussed in detail here. In brief, the camp is interpreted to have formed in a Sea-of-Japan-style back-arc basin that opened by rifting of continental crust in the Early Ordovician and closed by northwestward-directed subduction during Late Ordovician to Early Silurian time. The different groups mentioned above were deposited in different parts of this back-arc basin, which were tectonically juxtaposed in a subduction–obduction complex (Figure 2). Furthermore, the geochemistry of volcanic rocks and U–Pb radiometric dating (van Staal *et al.*, in press) show that the volcanic pile in each of the California Lake, Sheephouse Brook and Tetagouche groups, evolved from felsic-dominated to mafic-dominated through time. This change from felsic to mafic volcanism is interpreted in terms of crustal thinning during the rifting process, i.e., extended continental to transitional oceanic crust, respectively.

STRATIGRAPHY OF THE BATHURST MINING CAMP

Van Staal and Fyffe (1991) separated the rocks in the camp, part of the Miramichi Anticlinorium (Figure 1), into three groups, namely: Miramichi, Tetagouche and Fournier. Subsequent authors used this subdivision until the final results of the EXTECH II Project started to appear (cf. Wilson *et al.* 1998) and two additional groups, namely: California Lake and Sheephouse Brook, were separated from the Tetagouche Group.

The Cambrian(?) to Lower Ordovician Miramichi Group comprises a monotonous sequence of quartz wacke and slate of unknown thickness, which probably represents a flysch apron on the Gondwanan continental margin (van Staal and Fyffe 1991). Slate is more abundant and graphitic in the upper part (Knights Brook Formation) than in the lower part (Chain of Rocks Formation). Near the top of the Miramichi Group, the slate may contain abundant interbeds of volcaniclastic wacke with clear quartz and plagioclase phenoclasts (Patrick Brook Formation). Originally, these rocks were assigned to the Tetagouche Group (van Staal and Fyffe 1991) but they are now known to be part of the Miramichi Group (Fyffe *et al.* 1996). The Miramichi Group constitutes the Gander Zone in northern New Brunswick (van Staal and Fyffe 1991).

The Middle to Late Ordovician Fournier Group is divided into the Sormany and Millstream formations. The older Sormany Formation comprises pillow basalt and minor gabbro. The basalt is mainly primitive tholeiite with mid-ocean-ridge-basalt-like compositions but there are also compositions intermediate between mid-ocean-ridge basalt and oceanic-island basalt, reflecting the back-arc oceanic depositional setting (van Staal *et al.* 1992). The conformably overlying Millstream Formation consists of lithic and feldspathic wacke and slate with minor intercalated limestone and basalt. The Fournier Group, together with the three massive-sulphide-hosting groups described below, constitute the Dunnage Zone in northern New Brunswick.

Tetagouche Group

The Tetagouche Group comprises the Nepisiguit Falls, Flat Landing Brook, Little River and Tomogonops formations, in ascending stratigraphic order (Figure 2). These formations have been described previously (Langton 1994; Thomas *et al.* 2000; van Staal *et al.*, in press, and references therein) so only those hosting massive sulphide deposits are discussed below. The Tetagouche Group occurs in two major nappes (Figure 3) that constitute approximately half of the surface area of the Bathurst Mining Camp (Figure 1). The fossil and radiometric age control for the Tetagouche Group is shown in Figure 3. Both the Nepisiguit Falls and Flat Landing Brook formations contain massive sulphide deposits.

Nepisiguit Falls Formation: This formation hosts 23 of the 31 deposits in the Tetagouche Group (Table 1) and therefore is described here in some detail. The age of the Nepisiguit Falls Formation is constrained by several U–Pb isotopic ages and one fossil locality, which show an age of circa 470 Ma (Figure 3). Rocks of this formation were commonly referred to as "quartz augen (or eye) schists" (QAS or QES) and "quartz–feldspar augen schists" (QFAS) in the pre-1990 literature.

At the type locality, Grand Falls on Nepisiguit River (Figure 1), this formation is exposed intermittently for approximately 750 m along the river and is divisible into two parts. The lower third, about 200 m stratigraphically, comprises massive quartz–feldspar "porphyry," and the upper two thirds, about 400 m stratigraphically, comprises medium- to coarse-grained, quartz–feldspar-rich volcaniclastic rocks that are interlayered with aphyric tuff. The quartz–feldspar "porphyry" conformably overlies sedimentary rocks of the Miramichi Group and has a strike length many times its thickness. It typically has a vitreous, cryptocrystalline groundmass, contains less than 30% phenocrysts (up to 15 mm), and lacks any evidence of reworking (Figure 4a, 4b). The absence of magmatically broken crystals indicates that the emplacement mechanism was non-explosive, but the aspect ratio and lack of carapace breccias and hyaloclastites are atypical of subaqueous lava flows. Two possible genetic interpretations have been suggested for this porphyry (McCutcheon *et al.* 1993, 1997). One interpretation is that it formed subaqueously from volatile-

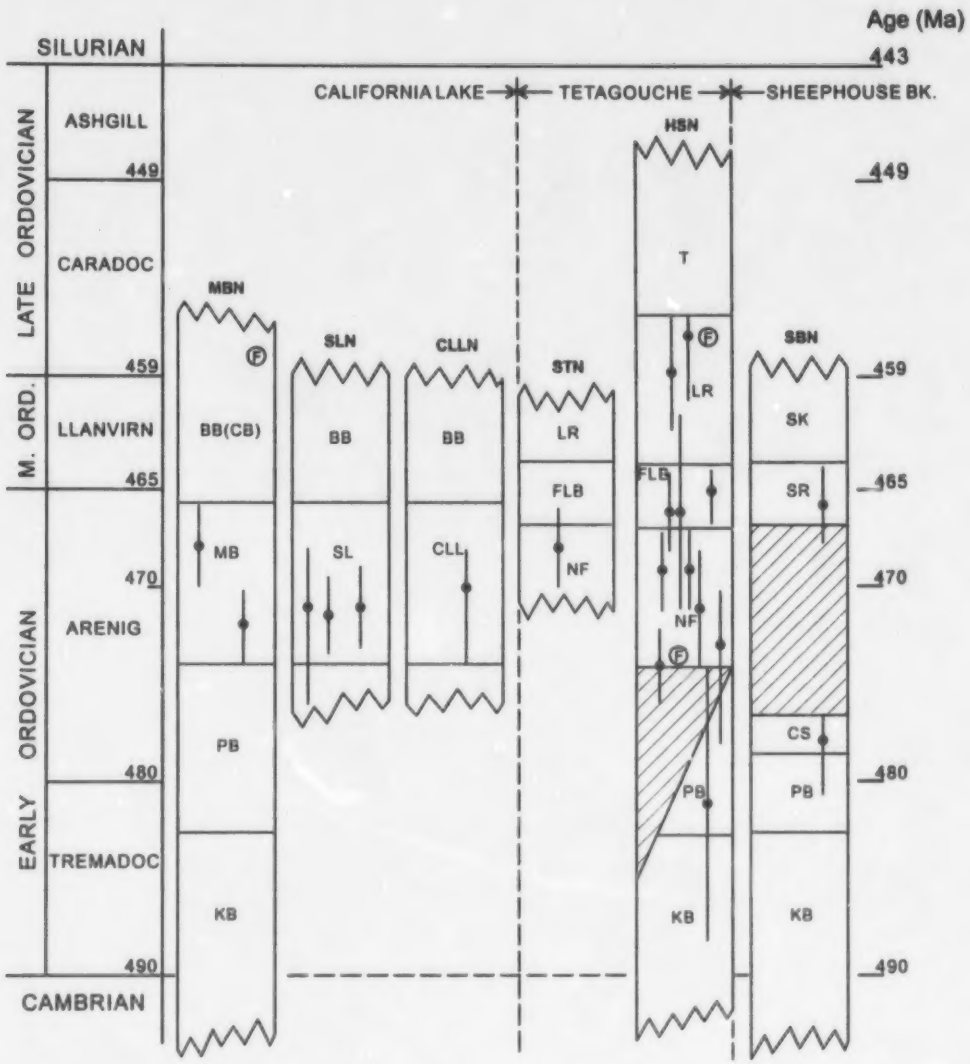

Figure 3. Time-stratigraphic representation (drawn to scale) of the Ordovician Period showing the age control on the various formations that comprise the California Lake, Sheephouse Brook and Tetagouche groups. Black dots with error bars are U–Pb radiometric ages referred to by van Staal *et al.* (in press). Diagonal ruling represents a time of nondeposition (disconformity). Formation abbreviations are as follows: **BB(CB)** – Boucher Brook Formation, Camel Back Member; **CLL** – Canoe Landing Lake Formation, **CS** – Clearwater Stream Formation; **FLB** – Flat Landing Brook Formation, **KB** – Knights Brook Formation; **LR** – Little River Formation; **MB** – Mount Brittain Formation; **NF** – Nepisiguit Falls Formation; **PB** – Patrick Brook Formation; **SK** – Slacks Lake Formation; **SL** – Spruce Lake Formation; **SR** – Sevogle River Formation and **T** – Tomogonops Formation. Nappe abbreviations are as follows: **CLLN** – Canoe Landing Lake Nappe; **HSN** – Heath Steele Nappe; **MBN** – Mount Brittain Nappe; **SBN** – Sheephouse Brook Nappe; **SLN** – Spruce Lake Nappe and **STN** – Strachans Lake Nappe.

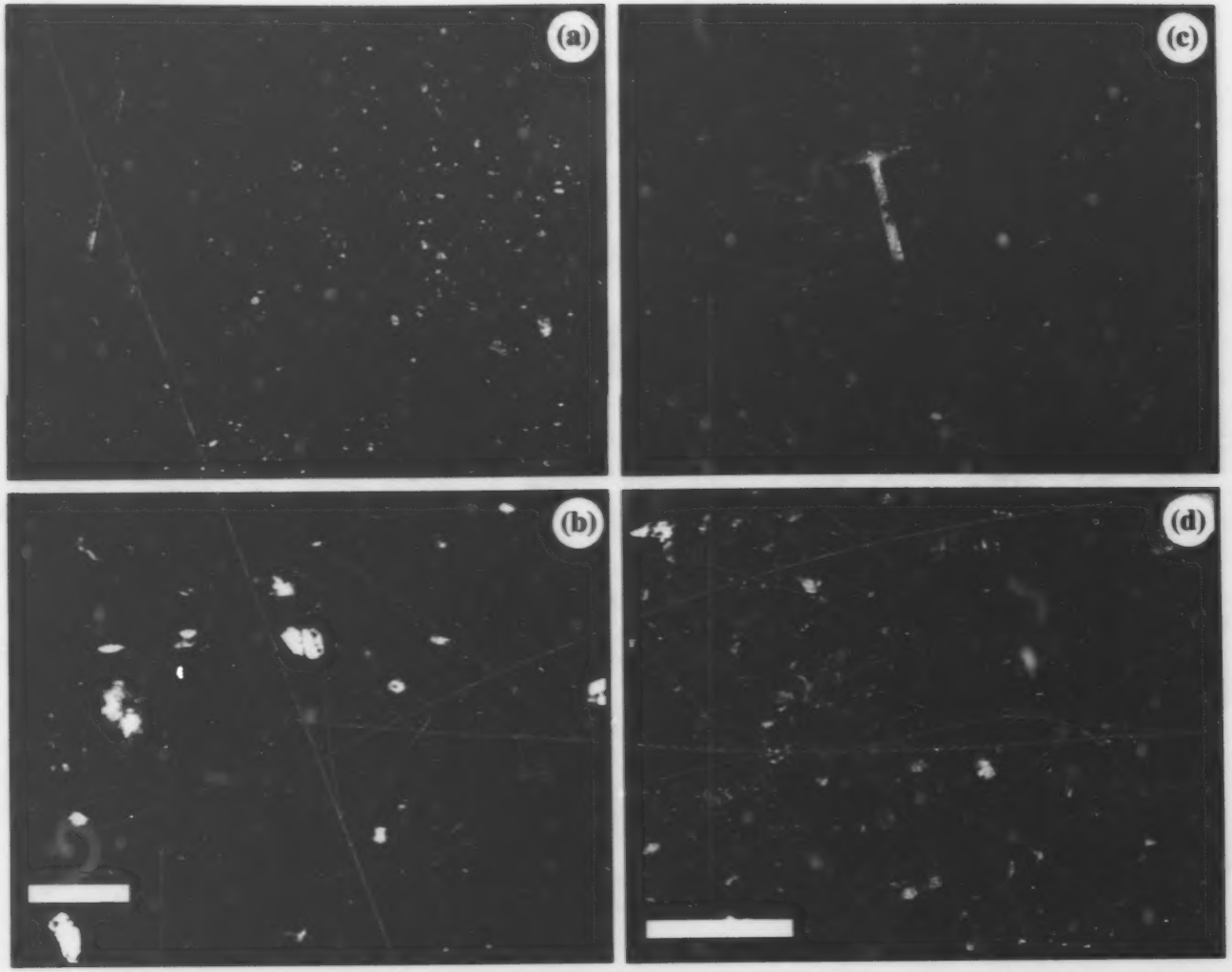

Figure 4. Nepisiguit Falls Formation. (a) Typical quartz–feldspar porphyry; hammer handle is about 40 cm long. (b) Cut slab of porphyry showing subhedral feldspar (white) and quartz (dark gray); bar scale is 1 cm. (c) Interbedded coarse- and fine-grained volcaniclastic rocks (crystal tuffs); hammer handle is about 40 cm long. (d) Cut slab of coarse-grained crystal tuff showing angular feldspar (light gray) and quartz (dark gray); bar scale is 1 cm.

rich magma that remained non-explosive because of the confining pressure of the overlying water column. Notably, rocks with characteristics intermediate between tuffs and lava flows (tufflavas) have been described elsewhere (Cas 1978; Creaser and White 1991). However, first-erupted felsic lavas in any volcanic cycle are generally crystal poor and volatile rich (cf. Hildreth 1981). Therefore, the other (preferred) interpretation is that the porphyry represents a dominant-volume magma emplaced as a sill into its own early-erupted pyroclastic pile. This would readily explain the large crystal size and compositional homogeneity of the porphyry but is less compatible with its uniform cryptocrystalline groundmass.

The volcaniclastic rocks (crystal tuffs) appear to conformably overlie the massive quartz–feldspar "porphyry" and generally become finer grained and thinner bedded upsection (McCutcheon *et al.* 1993, 1997). They also contain abundant (30% or more), commonly broken and rounded, quartz and feldspar (mostly < 5 mm) in a very fine-grained granular matrix (Figure 4c, 4d), i.e., tuffite of Schmid (1981). They exhibit primary features such as crystal sorting and graded beds and probably formed from explosive underwater eruptions that were deposited as cold debris flows (see Stix 1991), the "subaqueous, water-transformed pyroclastic flow deposits" of Cas and Wright (1991). In the upper part of the section, some beds contain rare, lapilli-sized, lithic clasts of aphyric (ash) tuff or rhyolite (originally ash) tuff and, at the top of the section, chloritic mudstone and silicate iron formation are present.

At the top of the section, chloritic and locally magnetic mudstone (silicate iron formation) is interbedded with dark greenish grey, fine-grained volcaniclastic rocks, which constitute the "Brunswick Horizon" at the nearby Austin Brook and Brunswick 6 mine sites. The contact with massive rhyolite of the overlying Flat Landing Brook Formation is exposed and appears to be conformable.

Elsewhere, the Nepisiguit Falls volcanic pile exhibits lateral variations in thickness and proportions of rock types. At Little Falls on Tetagouche River (Figure 1), the section is only about 30 m thick and mainly composed of interbedded aphyric tuff and fine-grained crystal tuff, with isolated lenses (channels) of coarse-grained volcaniclastic rocks. The coarse-grained rocks contain more than 50% crystals (quartz and feldspar) and a few intraformational clasts. Quartz–feldspar "porphyry" is conspicuously absent. This section, which represents the distal facies of the Nepisiguit Falls Formation (Langton and McCutcheon 1993), overlies calcareous rocks of the Vallée Lourdes Member (formerly formation) that unconformably overlies the Patrick Brook Formation (cf. Fyffe *et al.* 1997).

At Heath Steele, the Nepisiguit Falls formation contains "porphyry" but it overlies the volcaniclastic rocks rather than underlies them as in the type section. The volcaniclastic rocks are interbedded with quartz wacke and carbonaceous shale, which are typical of the upper part of the underlying Miramichi Group (Lentz and Wilson 1997). This implies that the contact between the Tetagouche and Miramichi groups is conformable at this locality rather than disconformable as it is in some places (cf. van Staal 1994).

Flat Landing Brook Formation: This formation hosts 8 of the 31 deposits in the Tetagouche Group (Table 1). It comprises aphyric to feldspar-phyric (± quartz) rhyolitic flows, hyaloclastites, and crackle breccias (Figure 5), interbedded with minor aphyric tuff, basalt, mudstone and iron formation. In the past, many of these rocks were interpreted as pyroclastic deposits, but now most are considered to be the products of lava flows (van Staal 1987; Wilson 1993). Feldspar ± quartz phenocrysts are small (1–3 mm) and constitute less than 10% of the rocks; the matrix is cryptocrystalline. The aphyric tuff and basalt appear to be most abundant in the northwestern (upper) part of the Bathurst Mining Camp where they constitute separate mappable members. The Flat Landing Brook Formation is a few million years younger

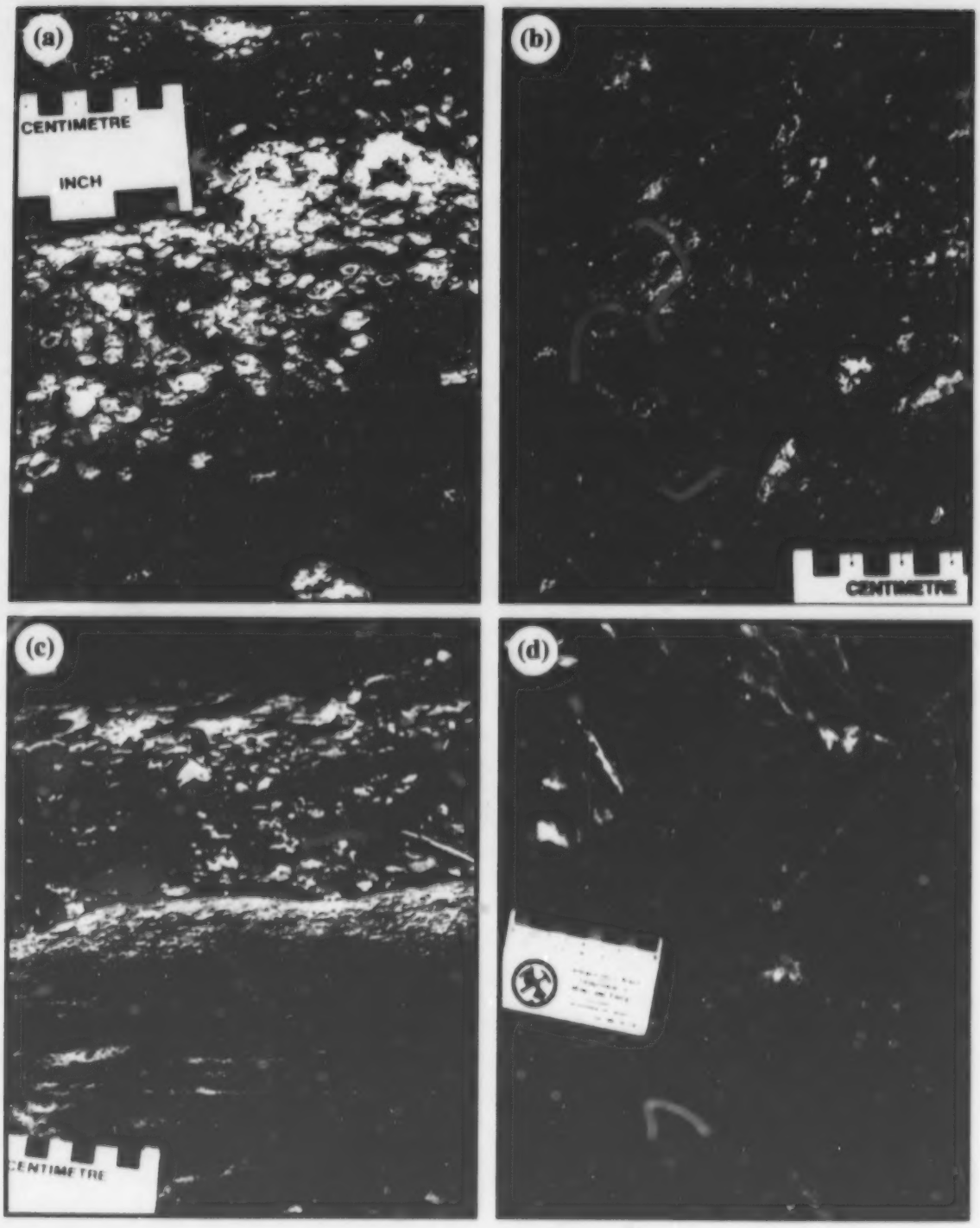

Figure 5. Flat Landing Brook Formation. (a) Spherulitic aphyric rhyolite. (b) Fragmental monolithic (autobrecciated) rhyolite. (c) Bedded aphyric tuff in the upper part of the formation. (d) Bedded aphyric tuff showing well-developed cleavage at a high angle to the layering. The scale bar on each photo is in centimetres.

than the Nepisiguit Falls Formation (Figure 3) and is interpreted as the product of second stage partial melting of granulitic lower crust (Lentz and Goodfellow 1992).

California Lake Group

The California Lake Group comprises the Mount Brittain, Spruce Lake, Canoe Landing Lake and Boucher Brook formations. The latter formation overlies each of the first three in three separate nappes that are named after their characteristic volcanic unit (see van Staal *et al.*, in press). The Mount Brittain nappe is the structurally lowest and the Canoe Landing Lake nappe is the highest (Figure 2). Collectively, the three nappes make up the California Lake Group and account for about 15% of the surface area of the Bathurst Mining Camp (Figure 1). The fossil and radiometric age control for this group is shown in Figure 3. The Mount Brittain, Spruce Lake and Canoe Landing Lake formations are more or less coeval and all contain massive sulphide deposits.

Mount Brittain Formation: This formation hosts 2 of the 13 deposits in the California Lake Group (Table 1). It is predominantly composed of feldspar-crystal and lithic felsic tuffs (Figure 6a, 6b) with minor interbeded aphyric tuff and aphyric rhyolite, but also includes a thin sedimentary unit (Charlotte Brook Member) at the base, which gradationally overlies rocks of the Miramichi Group. This sedimentary unit hosts the Murray Brook deposit and comprises dark grey shales and wackes with a few thin tuff beds. Gower (1996) originally included this unit in the Patrick Brook Formation but it has been reassigned to the California Lake Group because of its volcanic component (van Staal and Rogers 2000a). Even though this formation is about the same age as the Spruce Lake Formation (Figure 3), no direct linkage (interfingering) between the two formations exists. Lithologically, the Mount Brittain feldspar-crystal tuff more closely resembles quartz-poor Nepisiguit Falls crystal tuff that crops out south of Murray Brook (URN 414 in Figure 1) than it does Spruce Lake crystal tuff.

Spruce Lake Formation: This formation hosts 10 of the 13 deposits in the California Lake Group (Table 1). It mainly comprises feldspar-phyric to aphyric felsic volcanic rocks (Figure 6c, 6d), in places with intercalated tholeiitic basalt. Some dark grey to black, fine-grained sedimentary rocks, which overlie, underlie and/or are interbedded with this volcanic pile, are also included in this formation. The basalt is correlative with rocks in the Canoe Landing Lake Formation (van Staal *et al.*, in press) and shows that there was a direct linkage between these two formations.

Canoe Landing Lake Formation: This formation hosts only 1 of the 13 deposits in the California Lake Group (Table 1). It predominantly consists of pillow basalts and associated rocks, including interflow chert and red shale, but also contains some fine-grained, dark grey sedimentary rocks and minor felsic volcanic rocks. The felsic volcanic rocks are lithologically similar to those in the Spruce Lake Formation.

Sheephouse Brook Group

The Sheephouse Brook Group comprises the Clearwater Stream, Sevogle River and Slacks Lake formations (Figure 2). The first formation hosts the only known deposit in the group (Table 1). All these units have been described previously (Wilson *et al.* 1999; Thomas *et al.* 2000). The fossil and radiometric age controls for the Sheephouse Brook Group are shown in Figure 3. This group makes up about 5% of the surface area of the Bathurst Mining Camp.

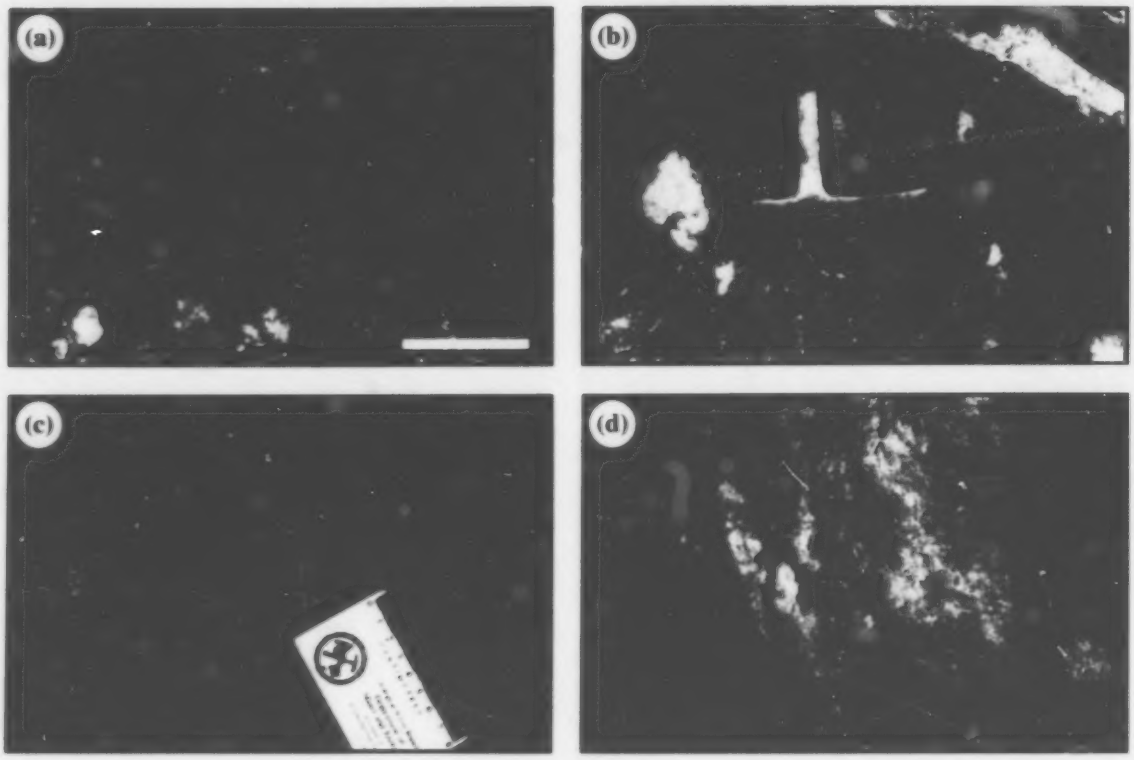

Figure 6 (a) Close-up of lithic-crystal tuff of the Mount Brittain Formation; bar scale is 1 cm. (b) Lithic-crystal tuff of the Mount Brittain Formation; hammer head is approximately 18 cm long. (c) Typical feldspar-crystal tuff of the Spruce Lake Formation; divisions on scale are centimetres. (d) Fragmental texture in Spruce Lake Formation; hammer head at top right is 4.5 cm in diameter.

Clearwater Stream Formation: Fyffe (1995) defined this formation, which hosts the Chester deposit, as "the plagioclase-phyric felsic volcanic rocks that immediately overlie sedimentary rocks of the Patrick Brook Formation south of the Moose Lake shear zone." These volcanic rocks are dacitic crystal tuffs that are about 10 000 000 years older than the felsic volcanic rocks in the California Lake and Tetagouche groups (Wilson *et al.* 1999).

SETTINGS OF MASSIVE SULPHIDE DEPOSITS

Of the 45 known deposits in the Bathurst Mining Camp (Table 1), 31 are hosted by the Tetagouche Group, 13 are in the California Lake Group and one is in the Sheephouse Brook Group. Of the 22 deposits with more than 1 000 000 t of delineated resources, the breakdown by group is 14, 7 and 1, respectively. Clearly, the Tetagouche Group contains the majority of the known deposits in the camp. The stratigraphic positions and characteristics of deposits in each group are described below.

Tetagouche Group

The stratigraphic distribution of massive sulphide deposits in the Tetagouche Group with respect to the Miramichi Group contact is illustrated in Figure 7. The first eight columns show the settings of deposits

in the Nepisiguit Falls Formation; the last three, deposits in the Flat Landing Brook Formation. The columns are graphic logs of actual drill cores, identified by deposit name and drill hole number, showing the end-of-hole (EOH) depth in metres and the number, e.g. 474256, of the source assessment file report (New Brunswick Department of Natural Resources and Energy files), or company, from which the information was obtained. Four of the cores, Key Anacon, Pabineau, Halfmile Lake and Heath Steele B-Zone, are plotted upside down in order to be stratigraphically right-way-up. Three of the cores, one from Brunswick 12, another from Halfmile Lake, and the third from Heath Steele B-Zone, have been described in detail by Lentz and Goodfellow (1993a, 1993b), Adair (1992) and Lentz *et al.* (1997), respectively. A geological plan and cross section, as well as geophysical plans and profiles, of each deposit illustrated in Figure 7, except Pabineau and Louvicourt, can be found in Thomas *et al.* (2000).

Deposits in the Nepisiguit Falls Formation share the following common characteristics, not illustrated in Figure 7:

- The massive sulphides are underlain by chloritic mudstone and/or very fine-grained volcaniclastic rocks (McCutcheon 1992), which generally have an areal extent equal to or larger than the deposit.
- Most are capped by and/or have a laterally equivalent oxide iron formation that is interbedded with and passes into chloritic (silicate) iron formation along strike (Saif 1983; Peter and Goodfellow 1996).
- Various alteration facies can be recognized in the footwall volcanic rocks (Lentz and Goodfellow 1994), including proximal silicic–Fe chloritic, Fe-chloritic (± sericitic), Fe–Mg chloritic–sericitic, distal sericitic–Mg chloritec, and least altered (regional metamorphic).
- Large-scale mineralogical and/or chemical zonation may be present, both vertically and laterally, in the deposits (Lusk 1969; Goodfellow 1975; Jambor 1979; Adair 1992; Luff *et al.* 1992). For example, vertical zonation in the Brunswick 12 deposit comprises four zones, from footwall to hanging wall: (1) massive to crudely layered pyrite, with variable amounts of pyrrhotite and chalcopyrite; (2) banded pyrite, sphalerite and galena, with minor chalcopyrite and pyrrhotite; (3) massive pyrite with thin discontinuous layers or lenses of sphalerite and galena, and (4) iron formation (all phases except hematite).
- Sulphide textures include massive, banded, fragmental, nodular, mosaic and stringer types (Figure 8 and see McCutcheon and Adair 1992).
- The $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios of deposits in the Tetagouche Group range from 18.187 to 18.279 and from 15.641 to 15.663, respectively; the $\delta^{34}S$ ranges from 11.8 to 16.5 per mil (data summarized in McCutcheon *et al.* 1993)

The eight Nepisiguit-Falls-hosted deposits portrayed in Figure 7 were selected to show various features. For example, the Key Anacon core transects a synclinal axis and shows that the massive sulphides, which grade 10.5% Pb +Zn over 7.7 m in a 1 to 1.4 ratio, only occur on one limb of the fold. The sulphides are at the top of the Nepisiguit Falls Formation and are directly overlain by basalts of the Little River Formation. Beneath the massive sulphide section, there is a chloritic alteration zone with disseminated pyrite, pyrrhotite and minor chalcopyrite, which is interpreted as the stockwork feeder to the deposit. No "porphyry" is present at this deposit but it does occur at the Key Anacon East deposit (URN 1384, Figure 1), approximately 1 km to the northeast.

The Brunswick 6 hole (B-347) cut barren oxide iron formation less than 100 m north of the perimeter of the open pit where more than 12 000 000 t of ore grading 7.6% Pb + Zn in a 1 to 2.5 ratio were mined. The iron formation that caps the sulphide body is directly overlain by massive rhyolite but it is not underlain by chloritic mudstone like the sulphides in the nearby open pit. This rhyolite is overlain by aphyric tuff or

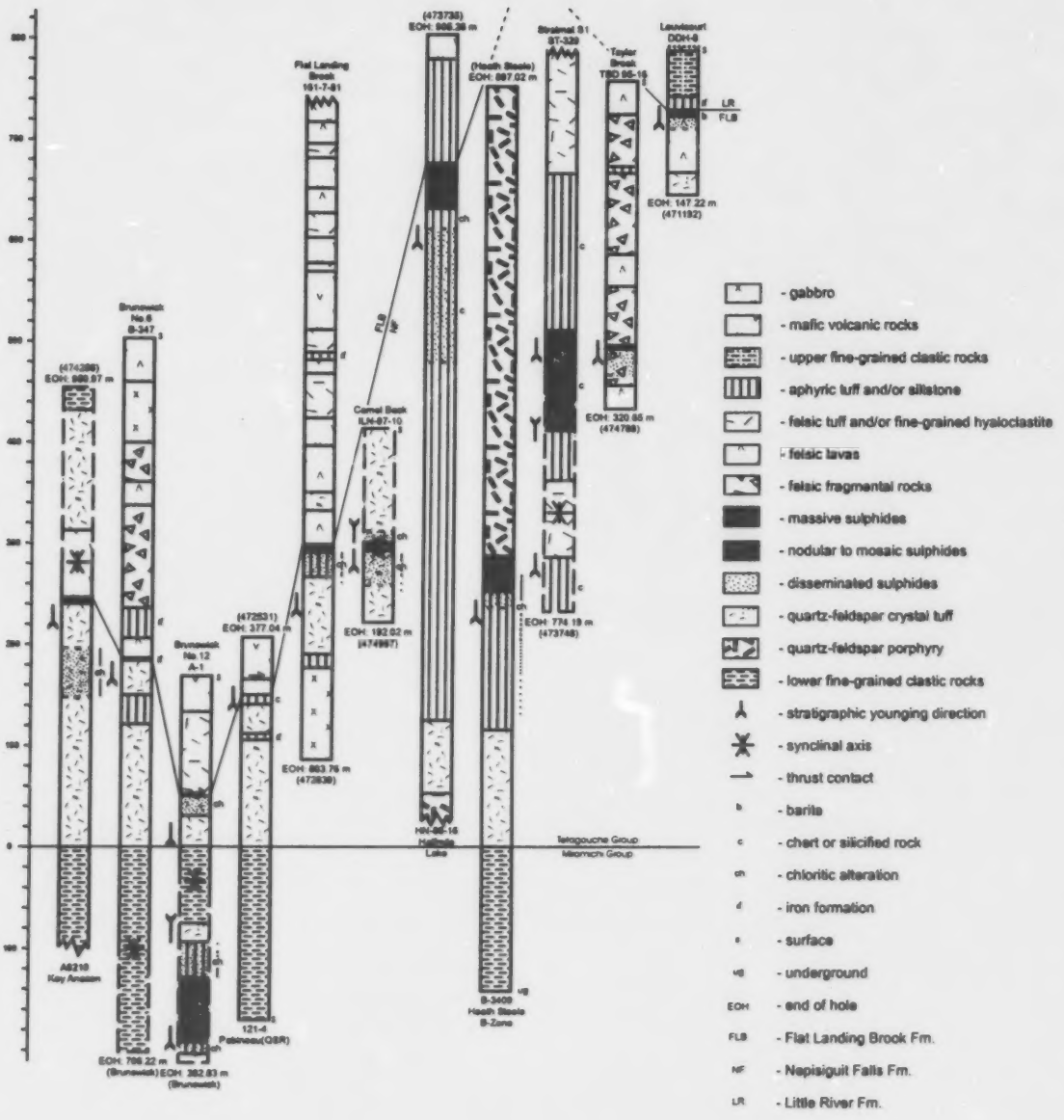

Figure 7. Graphic logs of diamond-drill holes from deposits in the Tetagouche Group. See text for explanation of other features. The scale to the left is in metres.

hyaloclastite that contains chloritic layers (pseudo iron formation). Massive "porphyry" is notably absent in or near the pit but occurs 250 m southeast of it.

The Brunswick 12 discovery hole (A-1) cuts a silicified stockwork zone containing disseminated sulphides (py + po), which is interpreted to be in fault contact with hanging-wall rocks (cf. Lentz and Goodfellow 1993a). Farther down the hole, the massive sulphides are underlain by chloritic mudstone and/or aphyric tuff that overlies volcaniclastic rocks (crystal tuffs); "porphyry" is absent in this hole but occurs elsewhere

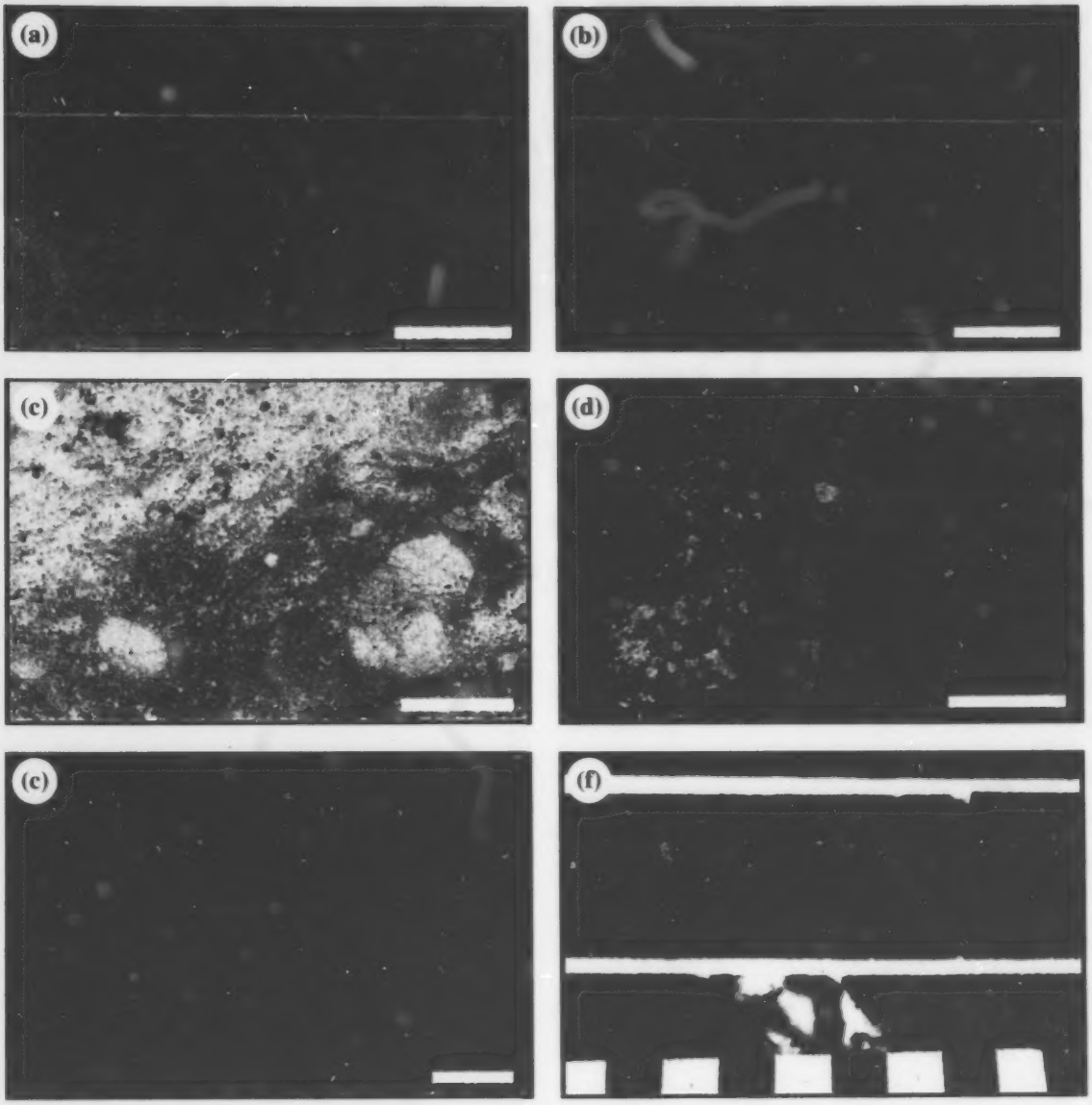

Figure 8. Cut slabs of drill cores from deposits hosted by the Nepisiguit Falls Formation. The bar scale on photos (a) to (e) is 1 cm. (a) Massive pyrite from the Brunswick 6 deposit. (b) Banded sphalerite–pyrite from Heath Steele C-zone. (c) Fragmental sulphides: pyrite, pyrrhotite and chalcopyrite from Heath Steele B-zone. (d) Stringer sulphides (pyrite and pyrrhotite) in chloritic mudstone from Brunswick 6. (e) Mosaic texture (*sensu* Maiklem *et al.* 1969) formed by pyrrhotite in highly chloritized mudstone from Halfmile Lake; previously called "breccia-matrix sulphides" by Adair (1992). (f) Nodular texture in chloritic mudstone from Brunswick 12; scale bar is in centimetres. The last two textures bear some similarities to "durchbewegung texture" but it implies a specific genetic connotation that is not invoked here.

in the mine. The massive sulphide section includes a 11 m interval grading 10.1% Pb + Zn in a 1 to 2.3 ratio, and a 24.4 m interval grading 5.9% Pb + Zn in a 1 to 4.6 ratio.

The Pabineau hole (121-4) intersected two exhalite horizons but no massive sulphides. The stratigraphically lowest one is a hematitic iron formation that overlies Nepisiguit Falls volcaniclastic rocks with weak chloritic alteration; the upper one is a chert that is overlain by highly deformed Flat Landing Brook rhyolite in thrust contact with basalt. The rocks between the two exhalites are very deformed but at least some of them have geochemical characteristics like the Nepisiguit Falls Formation (Walker 2000). Notably, the Headway deposit (URN 124, Figure 1) that is along strike to the east is within the Flat Landing Brook Formation but not far above the Nepisiguit Falls contact.

The Flat Landing Brook hole (161-7-81) also appears to contain two exhalite horizons. The lower one is described in the drill log as a "banded chert/chlorite (black) exhalite" with bands of massive to near massive sphalerite, galena, chalcopyrite, and pyrite. It contains a 4.3 m interval grading 18.5% Pb + Zn in a 1 to 1.4 ratio. This exhalite is overlain by Flat Landing Brook rhyolite, containing quartz-filled amygdules and/or lithophysae (described as "quartz augen" in the log), and underlain by aphyric tuff and crystal tuff, which are assigned to the Nepisiguit Falls Formation. Along strike, this exhalite passes into a banded oxide iron formation (Troop 1984). The upper exhalite is described as a "banded chert/chlorite iron formation" that is essentially devoid of sulphides. It is clearly within the Flat Landing Brook Formation like the chloritic layers in the Brunswick 6 hole. Notably, the Flat Landing Brook Formation contains some interbedded mafic tuffs in this hole.

The Camel Back hole (ILN-97-10) transects the core of a syncline, beginning and ending in fine-grained volcaniclastic rocks of the Nepisiguit Falls Formation. Layered massive sulphides, including 5.1 m of 11.1% Pb + Zn in a 1 to 3.9 ratio, occupy the core of the fold and overlie chloritic, volcaniclastic rocks interbedded with minor mudstone. The chloritic rocks in proximity to the massive sulphides contain disseminated to semi-massive nodular to mosaic sulphides (pyrite + pyrrhotite + chalcopyrite), similar to those reported by McCutcheon and Adair (1992).

The Halfmile Lake hole (HN-88-16) was collared in "porphyry", drilled through volcaniclastic rocks, and then cut a thick interval of mudrocks and aphyric tuff (no doubt structurally thickened) before intersecting sulphides. Nodular and mosaic sulphides, the "breccia-matrix sulphides" (pyrrhotite + pyrite + sphalerite + galena) of Adair (1992), underlie layered sulphides, are interbedded with them, and commonly extend laterally well beyond them; they constitute the bulk of the sulphide mineralization in the Halfmile Lake deposit. Within the 44 m interval of mineralized core, there are two high-grade zones about 20 m apart. The lower one is 9 m thick and grades 10.6% Pb +Zn in a 1 to 2.4 ratio and the upper one is 8 m thick and grades 11.1% Pb + Zn in a 1 to 8.8 ratio. A chloritic and silicified ("cherty") stockwork disseminated zone containing stringer pyrrhotite and minor chalcopyrite underlies the deposit.

The Heath Steele hole (B-3409), the only one in Figure 7 not collared at surface, cut layered massive sulphides underlain by semi-massive nodular and mosaic sulphides (pyrite + pyrrhotite + chalcopyrite) in chloritic mudstone, which assayed 1.5% Cu over 18.4 m. These sulphides are underlain by interbedded mudstone and fine-grained volcaniclastic rocks, which are also chloritic and contain disseminated sulphides, especially in proximity to the massive sulphide section. The significant difference between Heath Steele and other deposits is that the "porphyry" is in the hanging wall rather than the footwall.

Deposits in the Flat Landing Brook Formation share some common characteristics that are not illustrated in Figure 7:

- Most of the deposits are hosted by "cherty tuff" and/or fragmental rocks rather than mudstone.
- Oxide iron formation is absent, except at the Louvicourt deposit where red and green magnetic shales of the Little River Formation overlie the barite–sulphide exhalite.
- The main footwall alteration is sericitic and silicic; Fe-chloritic alteration is much less voluminous than it is in the Nepisiguit Falls Formation host rocks. In some deposits, talc is a significant constituent. Alteration extends into the hanging wall in at least one deposit.
- Metal zoning is generally absent.
- Sulphide textures include replacive, disseminated, stringer, semi-massive and banded types (Figure 9).
- The known Pb and S isotopic ratios are similar to those for deposits in the Nepisiguit Falls Formation.

The last three columns in Figure 7 were chosen to show different deposit settings in the Flat Landing Brook Formation. For example, the Stratmat S1 hole (ST-329) cuts a sulphide-bearing, tectonic mélange in the core of an antiform. The mélange is composed of blocks containing various proportions of massive to semi-massive sulphides, cherty tuff (aphyric tuff), and chloritic argillite (mudstone). Both up- and down-hole, the mélange passes into "broken formation" without sulphides, i.e., interbedded aphyric tuff and mudstone, and then into feldspar crystal tuffs of the "Northwall Sequence" (cf. Hamilton 1992; Park 1996). Talc is a common constituent in the sulphide-bearing mélange, which contains a 23.4 m interval grading 11.7% Pb +Zn in a 1 to 2.0 ratio.

The Taylor Brook hole (TBD-95-16) intersected a sequence of massive and fragmental rhyolites with some interbeds of aphyric tuff or hyalotuff. The sulphide deposit is largely disseminated and hosted by fragmental rocks; however, the massive exhalative part is hosted by "cherty to chloritic ash tuff." The massive section grades 9.9% Pb +Zn over 2.3 m in a 1 to 1.5 ratio. The underlying disseminated zone is chloritic and contains pyrite, pyrrhotite and trace amounts of chalcopyrite. Notably, pelecypods, which may represent a vent fauna, have been reported from this deposit (Gummer *et al.* 1978).

The Louvicourt hole (DDH-8) intersected a sulphide zone at the top of the Flat Landing Brook Formation. Red and green shales (locally magnetic), marking the base of the Little River Formation, overlie a thin "barite–sulphide" exhalite that grades 1.8% Cu, 1.9% Pb and 0.6% Zn over 2.7 m. This exhalite sits upon a "grey-white" fragmental rhyolite containing disseminated to semi-massive sulphides that grade 4.5% Pb + Zn in a 1.4 to 1 ratio over 5.6 m. This is the only deposit that contains significant barite in the Bathurst Mining Camp.

California Lake Group

The stratigraphic distribution of massive sulphide deposits in the California Lake Group with respect to the Miramichi Group contact is illustrated in Figure 10. The first column is from the Sheephouse Brook Group and will be discussed later. The second and third columns are from the Mount Brittain Formation and the last column is from the Canoe Landing Lake Formation; the other five are from the Spruce Lake Formation. The first eight columns are plotted at twice the scale of the last two. The columns are portrayed in a similar manner to those in Figure 7. Two of the holes, Armstrong B and Wedge, are plotted upside down in order to be stratigraphically right-way-up. Two of the holes, Caribou (C62-99) and McMaster

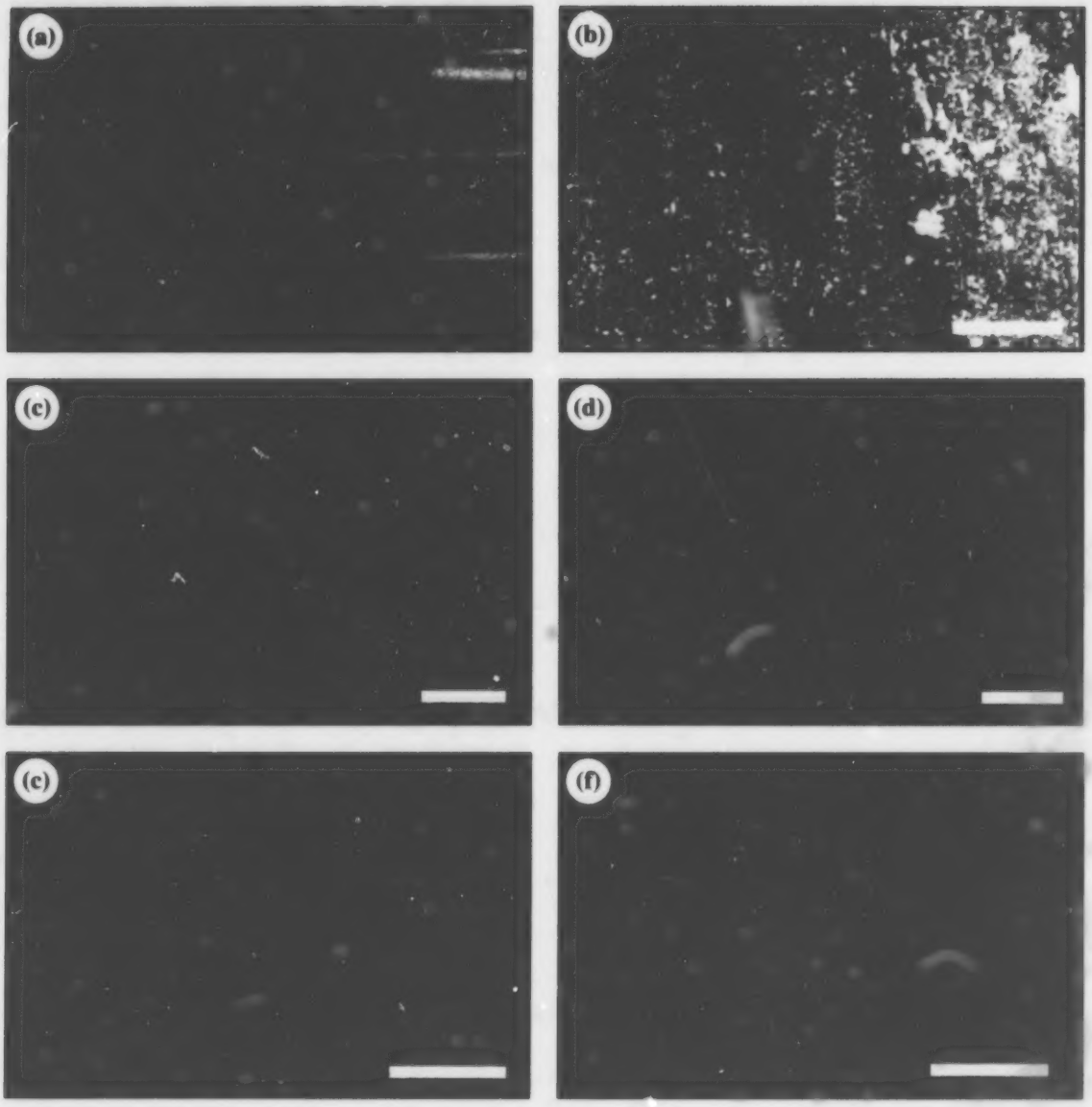

Figure 9. Cut slabs of drill cores from deposits hosted by the Flat Landing Brook Formation. (a) Replacive sulphides in chloritic hyaloclastite from Taylor Brook (core diameter is about 3.5 cm). (b) Close-up of replacive sulphides in chloritic tuff or mudstone from Stratmat Main. (c) Disseminated sulphides in silicified host rock at Taylor Brook. (d) Stringer sulphides in silicified host rock at Stratmat North. (e) Semi-massive sulphides from Stratmat Boundary. (f) Banded sulphides from Stratmat Main. The bar scale on photos (b) to (f) is 1 cm.

(MM-6), are described elsewhere (see Goodfellow, in press, and Jambor 1982, respectively). A geological plan and cross section, as well as geophysical plans and profiles, of each deposit illustrated in Figure 10, except Armstrong A and McMaster, can be found in Thomas *et al.* (2000).

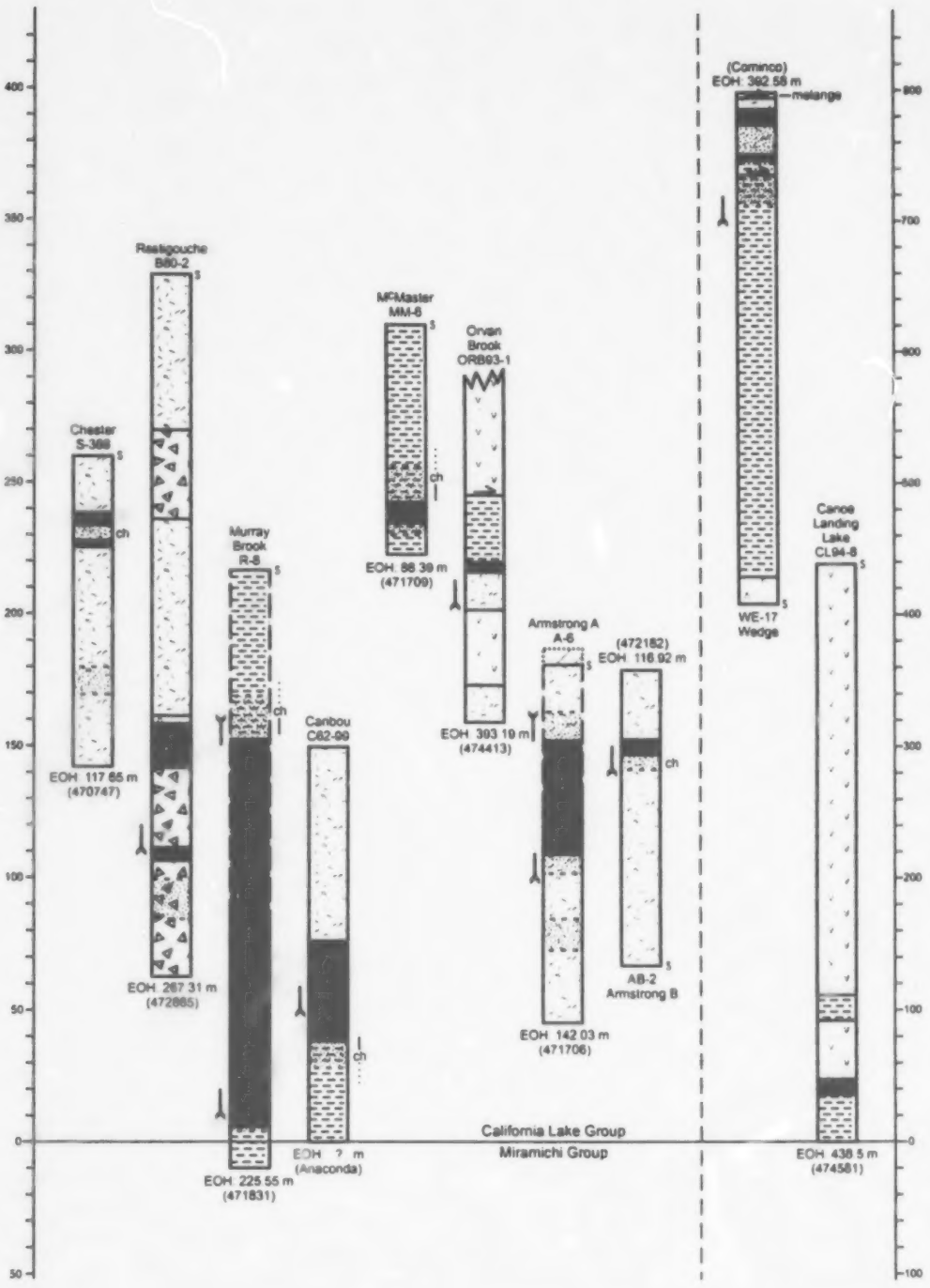

Figure 10. Graphic logs of diamond-drill holes from deposits in the California Lake Group and one (Chester) from the Sheephouse Brook Group. Legend as in Figure 7. Scale bars are in metres, the one on the right only applies to the columns right of the dashed vertical line.

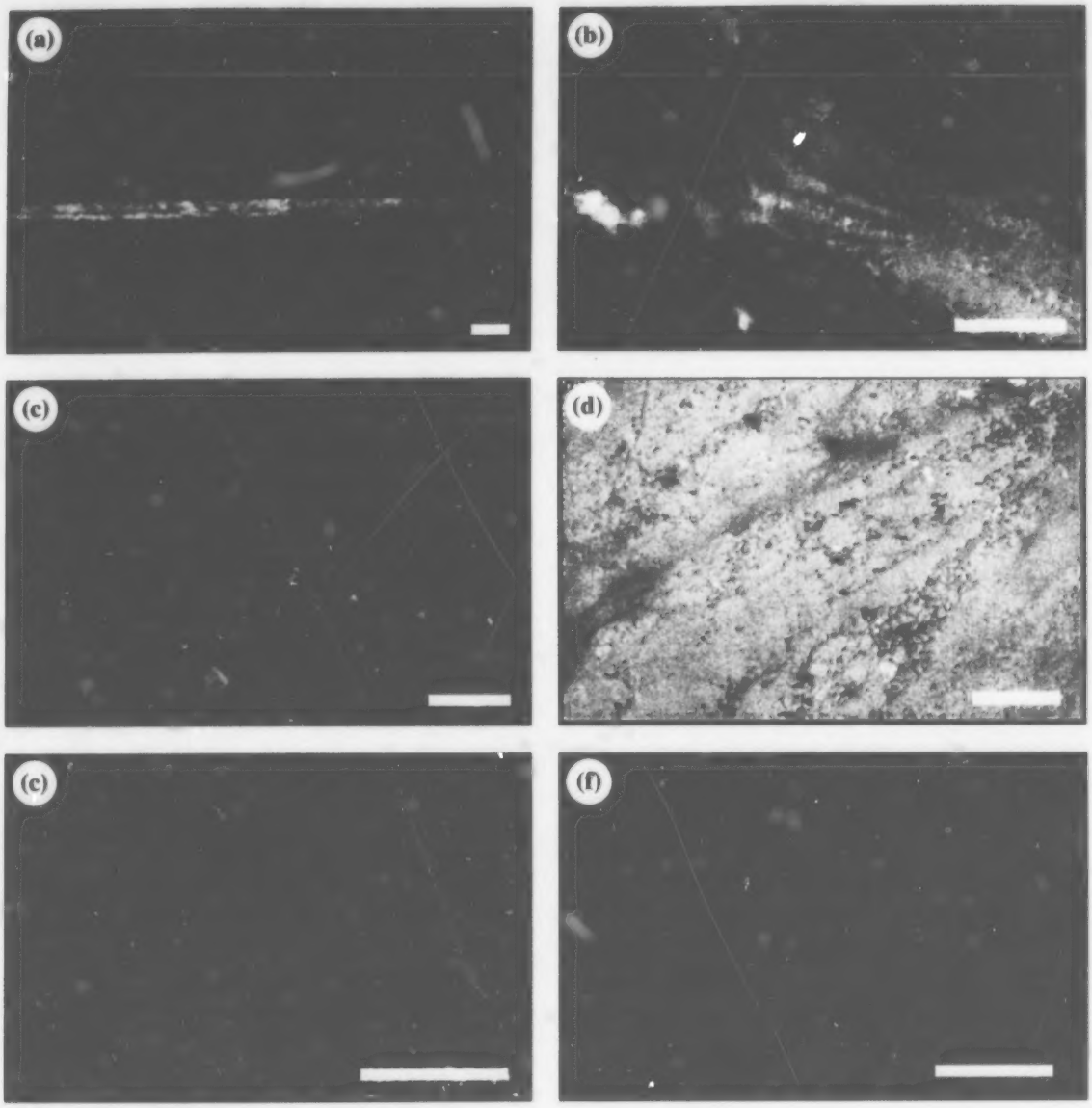

Figure 11. Cut slabs of drill cores from deposits hosted by the California Lake Group. The bar scale on each photo is 1 cm. (a) Bedded (transported) fragmental sulphides in greenish gray mudstone from Canoe Landing Lake. (b) Close up of banded layer within the bedded sulphides of Canoe Landing Lake. (c) Disseminated sulphides from Wedge. (d) Massive pyrite from Murray Brook. (e) Mosaic texture (*sensu* Maiklem *et al.* 1969) in highly chloritized mudstone from Murray Brook. (f) Banded sulphides from Orvan Brook.

Deposits in the California Lake Group share some common characteristics that are not shown in Figure 10:

- The host rocks may be either pelagic (rather than volcanogenic) sedimentary rocks or felsic tuffs.
- Oxide iron formation is absent but magnetite occurs within the sulphides at some deposits; at Caribou, this is attributed to late-stage, vent-proximal replacement of sulphides (Goodfellow, in press).
- Footwall alteration is either less obvious or not as extensive as it is in Nepisiguit-Falls-hosted

deposits. Beneath most deposits, Fe-rich chlorite and disseminated sulphides occur for a short distance into the footwall, but in the sediment-hosted deposits, at least some of this alteration may be related to downward- rather than upward-moving fluids. A silicified zone is absent from most deposits but hanging-wall sericitic alteration occurs in many.

- Metal zoning is manifested in the large deposits like Caribou, where a vertically zoned "vent complex" grades upward and laterally from brecciated massive pyrite with variable amounts of pyrrhotite, chalcopyrite and magnetite into "bedded sulphides" comprising pyrite, sphalerite, galena, arsenopyrite and tetrahedrite (Goodfellow, in press).
- Sulphide textures include bedded, disseminated, massive, fragmental, mosaic and banded types (Figure 11).
- The $^{206/204}Pb$ and $^{207/204}Pb$ ratios of deposits in the California Lake Group range from 18.230 to 18.319 and from 15.647 to 15.669, respectively; the d ^{34}S ranges from 5.9 to 10.9 per mil (data summarized in McCutcheon *et al.* 1993).

The two Mount-Brittain-hosted deposits portrayed in Figure 10 show that massive sulphides may occur both within and below the volcanic pile, which has been dated at circa 470 Ma (Figure 3). The Restigouche hole (B80-2) intersected three sulphide zones in fragmental felsic rocks. The uppermost one, immediately beneath massive rhyolite, is 17.2 m thick and grades 14.4% Pb + Zn in a 1 to 1.3 ratio. The middle one is 4.7 m thick and grades 11.7% Pb + Zn in a 1 to 1.4 ratio. The lowermost one is semi-massive to disseminated, 14.8 m thick and grades 4.3% Pb + Zn in a 1 to 1.5 ratio. The lapilli tuffs between the two massive sulphide zones contain disseminated and stringer pyrite.

The Murray Brook hole (R-8) transects a synformal fold axis so the sulphide intersection is unusually thick; the footwall rocks are repeated, and no hanging-wall rocks are represented. However, along strike to the west the footwall sedimentary rocks are overlain by Spruce Lake felsic volcanic rocks. The footwall sedimentary rocks contain a few thin tuff beds and consequently are assigned to the Mount Brittain Formation.

The six Spruce-Lake-hosted deposits in Figure 10 were selected to illustrate that deposits occur below, within and above the felsic volcanic pile. For example, the Caribou hole (C62-99) cut layered, brecciated (mosaic) and stringer sulphides, which underlie feldspar-porphyritic Spruce Lake rocks dated at circa 470 Ma (Figure 3) and overlie graphitic shales that are geochemically similar to rocks of the Miramichi Group (see Goodfellow, in press) but are assigned to the Spruce Lake Formation. Beyond the end of the hole, they are inferred to be in thrust contact with younger rocks of the Camel Back Member of the Boucher Brook Formation (cf. van Staal and Rogers 2000a).

The McMaster hole (MM-6) intersected a sulphide zone that is entirely within fine-grained sedimentary rocks. Thinly interbedded, dark grey mudstones and fine-grained sandstones form part of a lengthy sedimentary band that also hosts the Orvan Brook deposit. These rocks are assigned to the Spruce Lake Formation but they share many characteristics of the Boucher Brook stratotype, which is in the same thrust nappe (cf. van Staal and Rogers 2000b, 2000c). The McMaster copper deposit is largely composed of transported (allogenic) pyrite with subordinate chalcopyrite, sphalerite and galena (Jambor 1982). The younging direction is equivocal because there are chloritic rocks up-hole and disseminated sulphides down-hole from the massive sulphide lens.

The Orvan Brook hole (ORB93-1) cut a sulphide zone at the contact between sedimentary and felsic volcanic rocks of the Spruce Lake Formation. The 3.4 m thick zone graded 8.4% Pb + Zn in a 1 to 3.9

ratio. Up-hole for about 1 m, the "argillite" is chloritic and contains disseminated pyrite. Down-hole for about 2 m, the felsic rocks are chloritic and contain minor pyrite. Farther down-hole, a basalt member, which is considered to be correlative with the Canoe Landing Lake Formation, is interbedded with the felsic rocks.

Both the Armstrong A (A-6) and Armstrong B (AB-2) holes cut massive sulphides within the felsic volcanic pile. The thick massive sulphide intersection in the first hole is both underlain and overlain by disseminated sulphides; this is attributed to a fold repetition. The sulphide intersection in the second hole has disseminated sulphides only in the down-hole position. Unfortunately, assay data are not available for either hole.

The Wedge hole (WE-17) cut two massive sulphide zones separated by a disseminated zone. The lower zone (stratigraphically) is 6 m thick and grades 0.4% Cu, 1.0% Pb and 3.5% Zn, whereas the upper zone is 10.7 m thick and grades 0.2% Cu, 2.0% Pb and 10.1% Zn. Between these two zones the host "rhyolite" contains disseminated pyrite and chalcopyrite, including a 1 m interval of 5.4% Cu and a 1.7 m interval of 4.4% Cu. Up-hole, but stratigraphically beneath the lower massive zone, there is another disseminated pyrite zone in "rhyolite" but it does not carry significant copper. The "rhyolite" that is reported in the drill log may be silicified "argillite" because the underlying sedimentary rocks become progressively more silicified in proximity to the deposit. These sedimentary rocks overlie rhyolite of the Spruce Lake Formation (Figure 10) and were considered to be part of the Nepisiguit Falls Formation by Walker and McCutcheon (1996), but van Staal and Rogers (2000b) included them in their Spruce Lake Formation. No doubt, they are stratigraphically equivalent to the sedimentary rocks at Orvan Brook (hole ORB93-1 in Figure 10), which may be equivalent to the Boucher Brook stratotype. Near the top of this sedimentary unit, interbedded volcaniclastic rocks have lithological and geochemical similarities to the Nepisiguit Falls Formation (cf. Walker and McCutcheon 1996).

The one deposit hosted by the Canoe Landing Lake Formation, represented by hole CL94-8 in Figure 10, sits at the contact between underlying sedimentary rocks and overlying basalt. The sedimentary rocks are now included in the Canoe Landing Lake Formation (van Staal and Rogers 2000b) but they were previously assigned to the Boucher Brook Formation (Walker and MacDonald 1995). The sulphide section in hole CL94-8 is approximately 25 m thick and divisible into two parts. The lower part comprises about 6 m of transported, pyrite–shale breccia overlain by 4.4 m of massive sulphides grading 0.6% Cu, 0.5% Pb, 2.0% Zn and 2.1 g/t Au. The upper part includes 2.5 m of pyrite–shale breccia followed by 11.8 m of massive sulphides grading 0.7% Cu, 0.8% Pb, 2.7% Zn and 1.5 g/t Au. Although not present in this hole, a nearby felsic tuff bed that is interlayered with basalt yielded a U–Pb radiometric age of circa 470 Ma (Figure 3), which shows that at least some of the Canoe Landing Lake basalts are the same age as the Mount Brittain and Spruce Lake formations.

Sheephouse Brook Group

Fyffe (1995) summarized the history and geological setting of the Chester deposit. This deposit lacks an oxide iron formation, like deposits in the California Lake Group. It also has isotopic signatures that are similar to deposits in that group, i.e., $^{206/204}$Pb and $^{207/204}$Pb ratios of 18.302 and 15.659, respectively; the average d ^{34}S value is 9.5 per mil (data from McCutcheon *et al.* 1993). Notably the host rocks are about 10 000 000 years older than the sulphide-hosting units in the other two groups.

A representative drill hole (S-388) from this deposit is shown graphically in Figure 10. This drill hole cut two massive sulphide zones relatively near surface and a disseminated (stringer) copper zone about 50 m farther down hole. The upper massive (mainly pyrite) zone is 5.5 m thick and grades 9.9% Pb + Zn in a 1 to 2.4 ratio; the lower massive zone is 2.0 m thick and grades 4.9% Pb + Zn in a 1 to 1.9 ratio. The two zones are separated by 6.5 m of "dark green chlorite schist" and "quartz–chlorite schist" containing "trace" copper. The stringer copper zone farther down-hole grades 1.6% Cu over a core length of about 9.4 m.

SYNOPSIS OF DEPOSIT CHARACTERISTICS

The characteristics of the deposits described above are summarized in Table 2. Most of the information in this table was compiled by W.M. Luff from the provincial Mineral Occurrence Database (cf. Rose and Johnson 1990), supplemented by unpublished data from industry files and observations of the writers. Two of the columns in this table, "Probable Original Geometry" and "Deposit Type," represent our interpretations of the data, based upon classification schemes modified from Large (1992) and Jambor (1979), respectively.

Large (1992) subdivided Australian massive sulphide deposits into ten groups based on depositional style or geometry and summarized their characteristics. Although polyphase deformation has modified the original geometry of the deposits in the Bathurst Mining Camp, we think that seven of his ten styles can be recognized, including classic mound, asymmetric mound, pipe, sheet, layered, stacked and distal reworked. The style-types are largely self-explanatory apart from the distinction between layered and sheet deposits, which depends on the presence or absence, respectively, of an extensive "copper-rich stringer zone."

Jambor (1979) classified the Bathurst Mining Camp deposits into proximal and distal categories with allochthonous and autochthonous subdivisions of each category. We retain his proximal and distal categories but make the distinction between stratiform and stratabound deposits as our primary division. The stratiform deposits are mainly sediment-hosted and divisible into proximal and distal categories, whereas the stratabound deposits are volcanic-hosted, largely replacive, and hence proximal by nature.

DISCUSSION AND CONCLUSIONS

The massive sulphide deposits of the Bathurst Mining Camp clearly occupy more than one stratigraphic position; the majority (31) of them are in the Tetagouche Group but a significant number (13) also occur in the more-or-less coeval California Lake Group; one deposit occurs in the Sheephouse Brook Group. The deposits in each group have distinct isotopic signatures indicating that they were spatially separated at the time of deposition. However, the Wedge deposit provides some evidence regarding the linkage between the Tetagouche and California Lake groups. At this deposit, Nepisiguit-Falls-like rocks stratigraphically overlie Spruce-Lake-like rocks, suggesting that at least parts of the Nepisiguit Falls Formation are younger than the Spruce Lake Formation.

Within the Tetagouche Group (Figure 7), massive sulphide deposits are largely concentrated in the first volcanic cycle, represented by crystal tuffs of the Nepisiguit Falls Formation. Most are hosted by chloritic mudrocks at or near the top of this formation, the so-called "Brunswick Horizon," and are associated with

Table 2. Summary of

URN	Deposit Name	Group[1]	Fm[2]	Footwall Rocks	Hanging-wall Rocks	Probable Original Geometry[3]	"Exhalative" Sulphide Modes[4]
0484	Armstrong A	CLG	SL	Feldspar crystal tuff	Feldspar crystal tuff	Mound	mu, ml
0482	Armstrong B	CLG	SL	Feldspar crystal tuff	Feldspar crystal tuff	Mound	mu, ml, ds
0054	Brunswick No. 12	TG	NF	Mudstone & quartz–feldspar crystal tuff	Aphyric tuff & mudstone	Asymmetric mound	mu, ml
0144	Brunswick No. 6	TG	NF	Mudstone & quartz–feldspar crystal tuff	Massive rhyolite	Mound	mu, ml
1383	Camel Back	TG	NF	Mudstone & aphyric tuff	Aphyric tuff	Layered	ml, sn
0242	Canoe Landing Lake	CLG	CLL	Mudstone & wacke	Mudstone & basalt	Layered (reworked distal)	ml, mf, sf, ds
0444	Caribou	CLG	SL	Mudstone & aphyric tuff	Feldspar crystal tuff	Asymmetric mound	mf, ml, sn, ds
0071	Chester	SBG	CS	Feldspar crystal tuff	Feldspar crystal tuff	Pipe	mu, sn, ds
0046	Flat Landing Brook	TG	NF	Aphyric & quartz–feldspar crystal tuffs	Amygdaloidal rhyolite	Mound	mu, ml
0409	Halfmile Lake	TG	NF	Mudstone & chert	Aphyric tuff	Layered	ml, sn
0396	Heath Steele B-Zone	TG	NF	Mudstone & quartz–feldspar crystal tuff	Quartz–feldspar porphyry	Layered	mu, ml
0014	Key Anacon	TG	NF	Aphyric & crystal tuffs; mudstone	Basalt	Mound	mu, ml
0147	Louvicourt	TG	FLB	Fragmental rhyolites	Red & green slates	Mound	mu, sn, ds
0477	McMaster	CLG	SL	Mudstone & wacke	Mudstone & wacke	Layered (reworked distal)	ml, sf, ds
0414	Murray Brook	CLG	MB	Mudstone, wacke & minor aphyric tuff	Feldspar crystal tuff	Layered or Sheet?	mu, ml, sn
0062	Orvan Brook	CLG	SL	Feldspar crystal tuff	Mudstone & wacke	Sheet	ml, sf, ds
0157	Pabineau	TG	FLB?	Aphyric & quartz–feldspar crystal tuffs	Tectonized rhyolite	Mound?	mu, ds
0139	Restigouche	CLG	MB	Aphyric tuff, rhyolite	Feldspar crystal-lithic tuff	Stacked lenses	mu, sn, ds
0252	Stratmat S-1	TG	FLB	Mudstone, chert & aphyric tuff	Feldspar crystal tuff	Sheet	ml, sn, ds
0400	Taylor Brook (Consolidated Morrison)	TG	FLB	Fragmental rhyolites & aphyric tuff	Massive rhyolite	Stacked lenses	mu, sn, ds
0052	Wedge	CLG	SL	Mudstone & quartz–feldspar crystal tuff	Tectonically cut out	Mound	mu, ml

Notes: [1] Abbreviations as follows: CLG – California Lake Group, SBG – Sheephouse Brook Group, TG – Tetagouche Group.

[2] Abbreviations as follows: FM – Formation; CLL – Canoe Landing Lake, CS – Clearwater Stream, FLB – Flat Landing Brook, NF –Nepisiguit Falls, MB – Mount Brittain, SL – Spruce Lake.

[3] Classification modified after Large (1992).

[4] Six types as follows: ds – disseminated (< 30%), mf – massive (> 60%) fragmental, ml – massive layered, mu – massive unlayered, sf – semi-massive (30–60%) fragmental, sn – semi-massive nodular to mosaic,

Deposit Characteristics

Sulphide Zonation	Stringer Zone	Oxide Iron Fm.	Sulphide Mineralogy[5]	Gangue Mineralogy[6]	Main Footwall Alteration[7]	Hanging-wall Alteration[7]	Deposit Type (see text)
None	None	None	py+sp+gn+cp	q+ch+car	Chloritic	Sericitic	Stratabound replacive
Lateral: Cu to Zn–Pb	Yes	None	py+po+cp+sp +gn	q+ch+car	Chloritic	Sericitic	Stratabound replacive
Vetical & lateral: Cu to Zn–Pb to py	Yes	Yes	py+sp+gn+po +cp+as+tet	q+ch+car	Chloritic, silicic	Carbonate	Stratiform proximal
Lateral & vertical: Cu to Zn–Pb to py	Yes	Yes	py+sp+gn+po +cp+as+tet	q+ch+car	Chloritic, silicic	None	Stratiform proximal
Lateral: Cu to Zn–Pb	None	Yes	py+sp+gn+cp	q+ch	Chloritic	None	Stratiform proximal
None	None	None	py+sp+gn+cp	q+ch	None	None	Stratiform distal
Lateral & vertical: Cu to Zn–Pb to py	None	None	py+sp+gn+cp +as	q+ch+car+mt	Chloritic	Sericitic	Stratiform proximal
Vertical: Cu to Zn–Pb	Yes	None	py+po+cp+sp +gn	q+ch+sc	Chloritic	Sericitic	Stratabound replacive
Lateral: Zn–Pb to Py	Yes	Yes	py+sp+gn+cp +po+as	q+ch+sc+mt	Chloritic	None	Stratiform proximal
Lateral & vertical: Cu to Zn–Pb	Yes	None	py+sp+gn+po +cp+as	q+ch+car	Chloritic	Carbonate	Stratiform proximal
Lateral & vertical: Cu to Zn–Pb	Yes	Yes	py+sp+gn+po +cp+as	q+ch+car+mt	Chloritic	Sericitic	Stratiform proximal
Lateral & vertical: Cu to Zn–Pb	Yes	Yes?	py+sp+gn+po +cp+as	q+ch+car+mt	Chloritic	Carbonate	Stratiform proximal
None	None	Yes?	py+sp+gn+cp +tet	ba+q+sc+ch	Sericitic	None	Stratabound replacive
None	None	None	py+cp+sp+gn	q+ch	Sericitic	Chloritic	Stratiform distal
Lateral & vertical: Cu to Zn–Pb to py	None	None	py+sp+gn+cp +as+tet	q+ch+car+mt	Chloritic	None	Stratiform proximal
None	None	None	py+sp+gn+tet+as	q+sc+car	Chloritic	Minor chloritic	Stratiform distal
None	None	None	py+sp+gn+cp	q+sc+car	Chloritic	None	Stratabound replacive
Vertical: Cu to Zn–Pb to py	None	None	py+sp+gn+cp +as+tet	q+ch+sc+car +mt	Chloritic	Silicic	Stratabound replacive
None	None	None	py+sp+gn+cp	q+sc+tc+car	Sericitic, silicic	Sericitic	Stratiform proximal
Lateral: weak Cu to Zn–Pb	Yes	None	py+sp+gn+po +cp	q+ch	Sericitic, chloritic	Sericitic	Stratabound replacive
Vertical: Cu to Zn/Pb	Yes	None	py+cp+sp+gn +tet	q+ch+car	Chloritic, silicic	Not preserved	Stratiform proximal

[5] Abbreviations as follows: as – arsenopyrite, cp – chalcopyrite, gn – galena, po – pyrrhotite, py – pyrite, sp – sphalerite, tet – tetrahedrite.

[6] Abbreviations as follows: ba – barite, car – carbonates (ankerite, siderite, dolomite and/or calcite), ch – chlorite, mt – magnetite, q – quartz, sc – sericite (white mica), tc – talc.

[7] Classification after Thompson and Thompson (1996).

oxide iron formation. However, at least one, the Heath Steele deposit, sits beneath quartz–feldspar porphyry, demonstrating that the top of the Nepisiguit Falls Formation is not the only place to look for massive sulphide deposits. Even if this porphyry represents a late-stage, dominant-volume magma that was emplaced as a near-seafloor sill, it nevertheless shows that Nepisiguit Falls magmatism had not ended when this deposit formed.

Other deposits are hosted by second-cycle volcanic rocks, such as the Flat Landing Brook Formation, and are associated with "cherty tuff" and/or fragmental felsic rocks with abundant sericitic alteration. Some of them, like the Stratmat deposits, appear to be relatively low in the volcanic pile, but at least one, Louvicourt, is at the top of the Flat Landing Brook Formation, demonstrating that not all deposits in this formation are in the same stratigraphic position. Compared to the Nepisiguit Falls-hosted deposits, these are generally smaller; however, the Stratmat S1 deposit, with about 5 000 000 t of resource (Table 1), is the exception.

Within the California Lake Group (Figure 10), most deposits are associated with first-cycle volcanic rocks of the Spruce Lake Formation and occur in three stratigraphic positions. For example, the Caribou deposit is hosted by dark grey shales at or near the bottom of this formation, whereas Armstrong A is within the felsic volcanic pile, and Orvan Brook is in fine-grained clastic rocks that overlie the volcanic pile. The Spruce Lake Formation interfingers with basalts of the Canoe Landing Lake Formation, which hosts at least one deposit The Canoe Landing Lake deposit, like Caribou, is in fine-grained sedimentary rocks at or near the bottom of the volcanic pile. The deposits in the Mount Brittain Formation occur in two positions: Murray Brook is hosted by sedimentary rocks beneath the main felsic volcanic pile, and Restigouche is located within the pile. Regardless of host formation, the largest deposits in the California Lake Group, i.e., Caribou, Canoe Landing Lake and Murray Brook (Table 1), are situated at or near the base of the group.

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THE CLOVERDALE As–Sb DISPERSAL TRAIN, AND OTHER TILL GEOCHEMICAL ANOMALIES IN THE WEST HALF OF THE COLDSTREAM (NTS 21 J/06) MAP AREA, CARLETON AND YORK COUNTIES, NEW BRUNSWICK †

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SEAMAN, A.A. 2001. The Cloverdale As–Sb dispersal train, and other till geochemical anomalies in the west half of the Coldstream (NTS 21 J/06) map area, Carleton and York counties, New Brunswick. *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 97–110.

An As–Sb dispersal train in till was previously identified in the Millville (NTS 21 J/03) map area, and attributed to an unknown source in the Coldstream (NTS 21 J/06) map area. Till geochemistry sampling in part of the west half of the Coldstream map area has identified the probable source of the dispersal train as mineralization in the Early Carboniferous Carlisle Formation red clastic sedimentary rocks in the vicinity of the dispersed community of Cloverdale. Elevated values of Au, Sn and W are also present in the till overlying or down ice of the Carlisle Formation. A belt of elevated As, Pb and Zn values in the north-central part of the Coldstream map area may represent a second dispersal train. This could be derived from known mineral occurrences to the north-northwest in the adjacent Juniper (NTS 21 J/11) map area (to the north). Elevated Pb values appear to be associated with the trend of the Woodstock Fault system in the southwestern corner of the study area, while elevated Hg values appear to be associated with the various splays of the Woodstock Fault system throughout the area.

Une suite de dispersion d'As–Sb dans le till avait auparavant été relevée dans le secteur cartographique de Millville (SNRC 21 J/03) et elle avait été attribuée à une source inconnue dans le secteur cartographique de Coldstream (SNRC 21 J/06). Un échantillonnage géochimique du till dans une partie de la moitié occidentale du secteur cartographique de Coldstream a circonscrit la source probable de la suite de dispersion à une minéralisation de roches sédimentaires clastiques rouges de la Formation du Carbonifère inférieur de Carlisle, à proximité de la communauté dispersée de Cloverdale. Des valeurs élevées d'Au, de Sn et de W sont également présentes dans le till recouvrant la Formation de Carlisle ou sur sa face aval. Une ceinture de valeurs élevées d'As, de Pb et de Zn dans le centre-nord du secteur cartographique de Coldstream pourrait représenter une seconde suite de dispersion. Celle-ci pourrait provenir de venues minérales reconnues au nord-nord-ouest dans le secteur cartographique voisin de Juniper (SNRC 21 J/11) (au nord). Les valeurs élevées de Pb semblent associées à la direction empruntée par le système de failles de Woodstock dans le coin sud-ouest du secteur d'étude, tandis que les valeurs élevées de Hg semblent liées aux diverses failles mineures divergentes du système de failles de Woodstock partout dans le secteur.

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† New Brunswick Geological Surveys Branch ordinary budget.

INTRODUCTION

Till geochemistry investigations in the Millville (NTS 21 J/03) map area in west-central New Brunswick (Figure 1) identified a south-southeast-trending belt (six contiguous sites) of elevated As and Sb values in the north-central part of the map area (Seaman 1998). Elevated Sn and W values were associated with some of these sites. This belt crosses the trend of the local bedrock units, and lies within and parallels a dispersal train of reddish coloured till derived from the red clastic sedimentary rocks of the Carboniferous Carlisle Formation (Seaman 1998). As a result of these characteristics, and its parallelism with pebble and geochemical dispersal trains in the adjacent Fosterville (NTS 21 G/13) map area (to the southwest) (Seaman 1994, 1995, 2000a), this belt was interpreted as a dispersal train, derived from an unknown source to the north-northwest (Seaman 2000a). Possible sources were suggested to be mineralization associated with the Woodstock Fault system, or a window through the Carlisle Formation into mineralized Devonian volcanic rocks (Seaman 1998).

During the summer of 1998 till sampling was begun in the Cloverdale area, in the south-central part of the Coldstream (NTS 21 J/06) map area (Figure 1) and to the north and northwest of the dispersal train. This sampling was continued during the summer of 2000 along the north-northwestward projection of the dispersal train (Figures 2 and 3). The objective of this part of the sampling program was to determine the extent of the dispersal train and the location of its bedrock source. In addition, sampling was completed for much of the remainder of the west half of the Coldstream map area, concentrating on the area adjacent to, or to the southeast of (down-ice from), the various splays of the Woodstock Fault system. The goal of this part of the sampling program was to assist in the evaluation of the mineral resource potential of the Woodstock Fault system within the area. Sampling was conducted using the standard 2 km grid (1 sample / 4 km^2) and the same sampling procedures as used in earlier till geochemistry investigations in the adjacent Millville (NTS 21 J/03) and Woodstock (NTS 21 J/04) map areas (e.g., Seaman 1997, 1998, 2000b).

The available surficial geology and till geochemistry data for the 1998 and 2000 Coldstream West sample sites is listed in detail in Seaman (2001). That report also includes description of the field and analytical methods, and comments regarding the reproducibility of analyses as indicated by the results obtained on analytical and field duplicate samples.

GEOLOGIC ENVIRONMENT

Bedrock geology

The bedrock geology of the Coldstream map area was mapped at a scale of 1 inch equals 1mile (1:63 360) by Anderson (1968). Detailed quarter-mile (1:15 840 scale) mapping was subsequently completed in much of the western half of the map area by St. Peter (1982) and Venugopal (1981, 1982). This work was summarized at 1:250 000 scale by Fyffe (1982). A 1:50 000 scale compilation of the bedrock geology of the area was also prepared by Fyffe (1984). The bedrock geology of the west half of the Coldstream map area is illustrated on Figures 2, 3 and 4. The bedrock unit descriptions (Table 1) are based on Fyffe (1984), St. Peter (1982) and Venugopal (1981, 1982). The bedrock unit boundaries were derived primarily from Fyffe (1982). However, the unit designations have been updated to 2000 standards (L.R. Fyffe, personal communication, 2000).

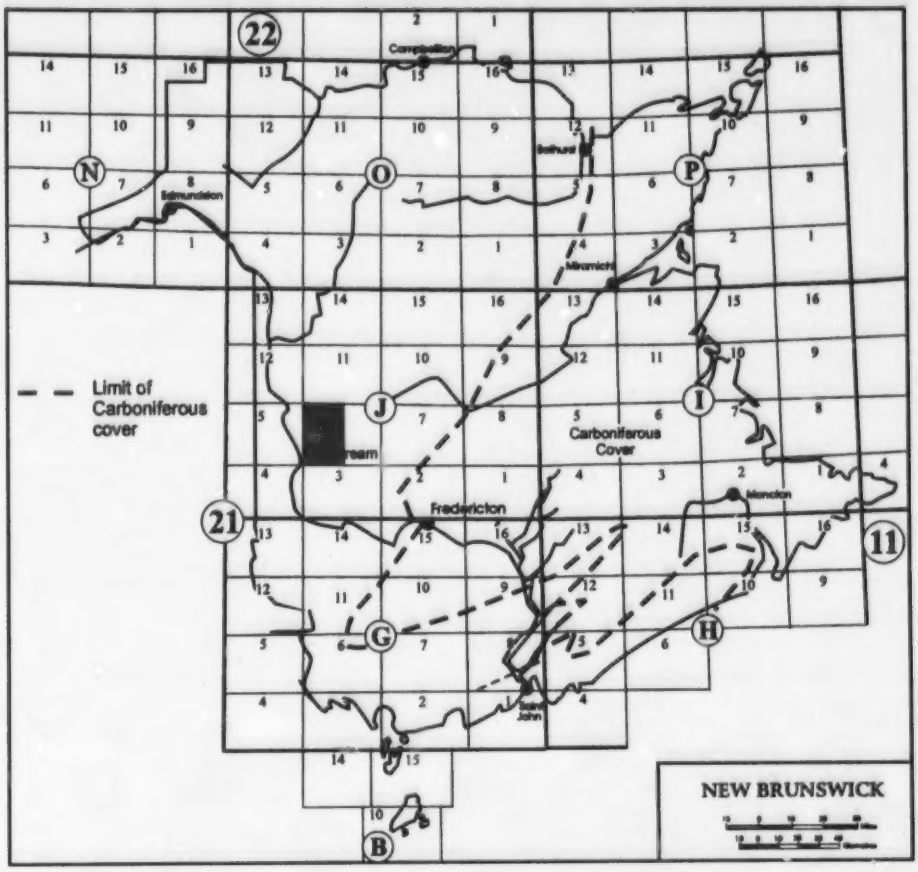

Figure 1. Location of the Coldstream West (NTS 21 J/06W) map area.

The Woodstock Fault system is a major northeast-trending fault that separates the Matapedia Cover Sequence to the northwest, from the Miramichi Terrane to the southeast (Fyffe and Fricker 1987). In the Coldstream West area, the Woodstock Fault system comprises three major northeast–southwest-trending faults: from west to east the Ashland–Highlands, Knowlesville and Howard Brook faults (St. Peter 1982). Two approximately north–south-trending faults, the Windsor to the west and Armond to the east, connect with the Ashland–Highlands and Knowlesville faults. The rocks to the northwest of the Ashland–Highlands Fault consist primarily of Ordovician to Silurian age marine calcareous and clastic sedimentary rocks (St. Peter 1982). Cambro-Ordovician marine clastic sedimentary rocks are present to the south of the Howard Brook Fault in the southwestern part of the study area (Venugopal 1981). These rocks were assigned to the Miramichi Group in previous till geochemistry investigations in west-central New Brunswick (e.g., Seaman 1997, 1998, 2000b) but are now assigned to the Woodstock Group (New Brunswick Department of Natural Resources and Energy 2000). They are in fault contact with Devonian marine to terrestrial clastic sedimentary and volcanic rocks to the east (St. Peter 1982). The latter are overlain by an outlier of Carboniferous terrestrial clastic sedimentary rocks (St. Peter 1982). Within the fault system, rocks from the adjacent Ordovician to Carboniferous age units are present.

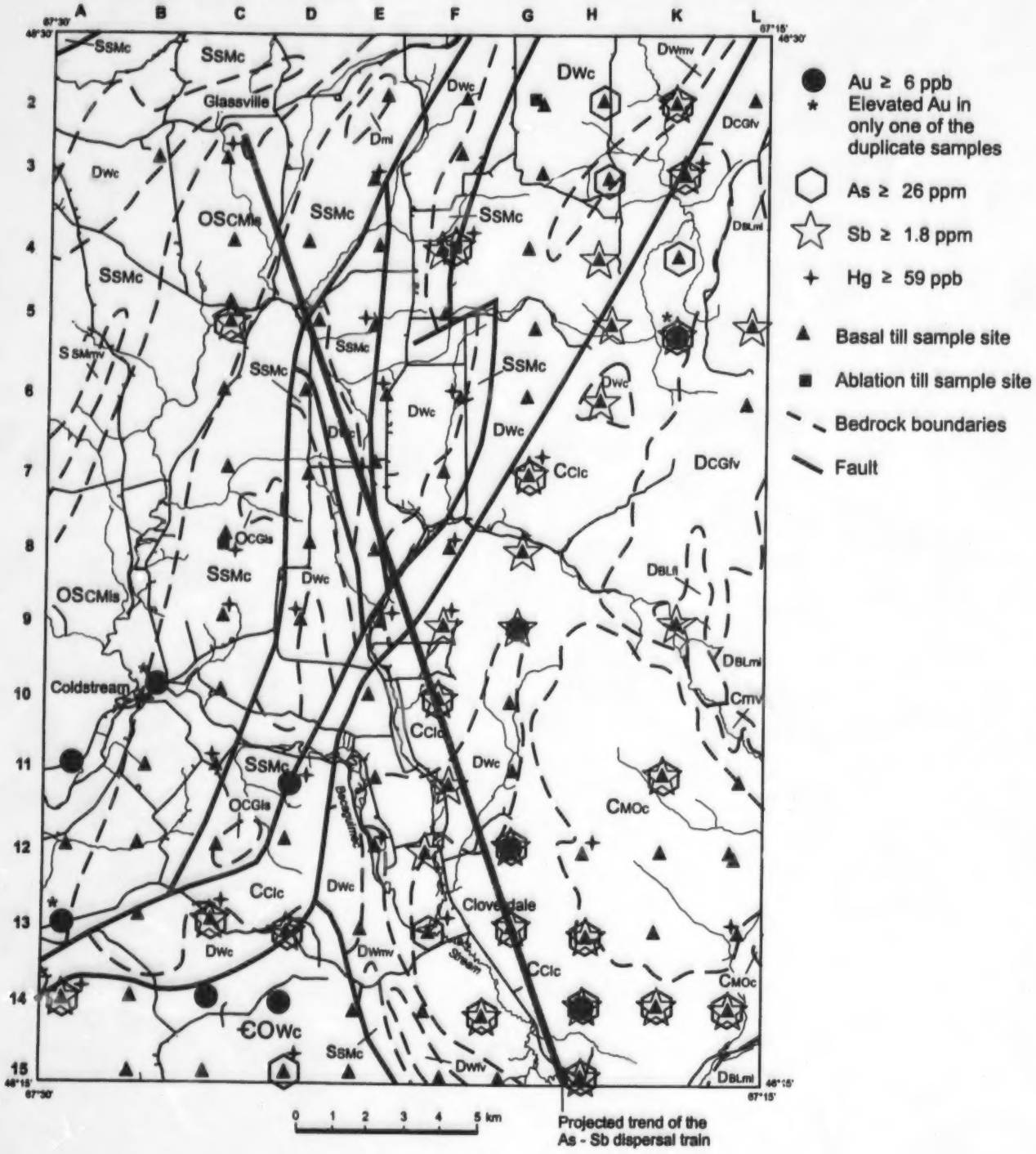

Figure 2. Bedrock geology, till sample site locations, and distribution of sites with elevated values for Au, As, Sb and Hg in the west half of the Coldstream map area.

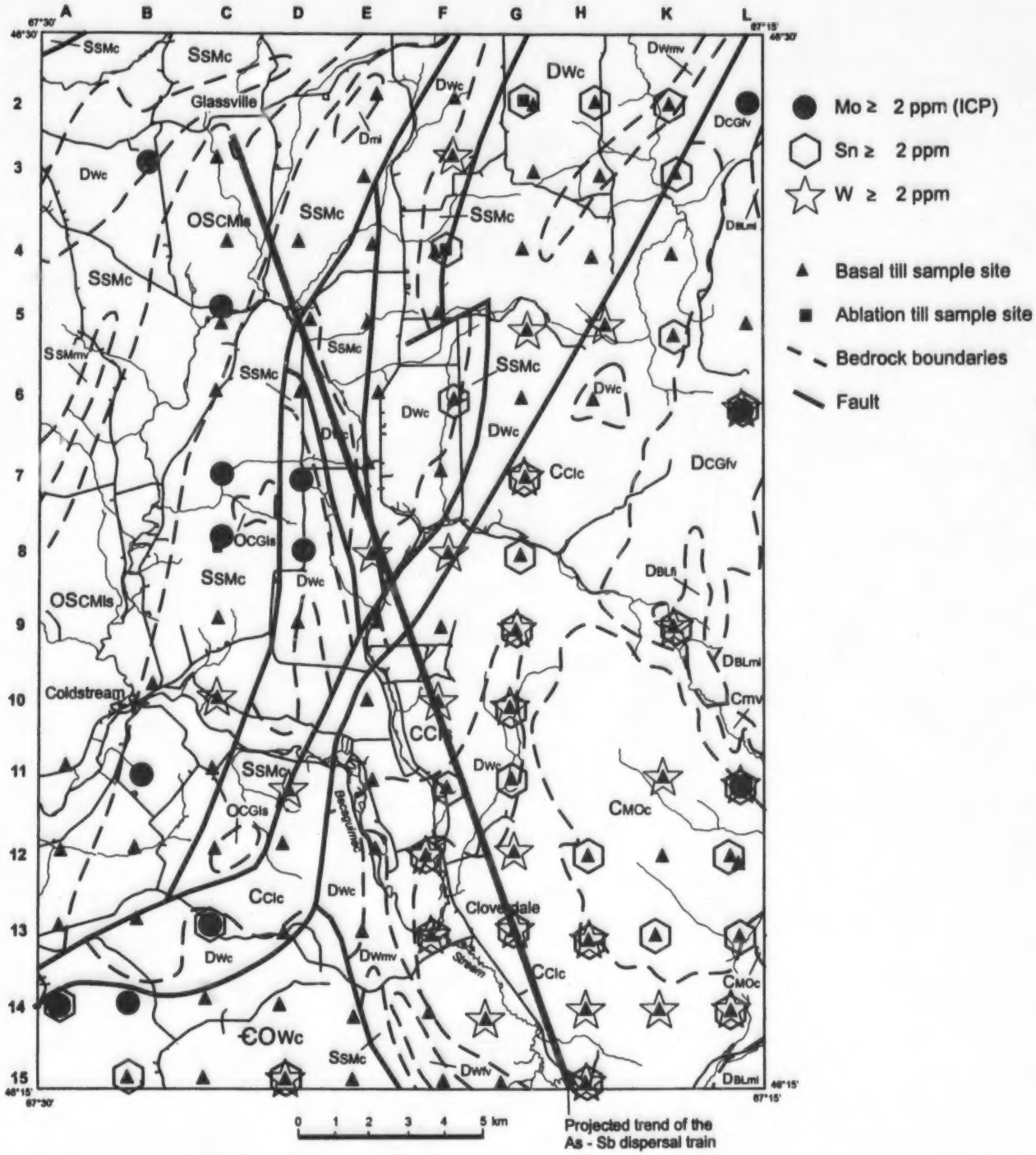

Figure 3. Bedrock geology, till sample site locations, and distribution of sites with elevated values for Mo, Sn and W in the west half of the Coldstream map area.

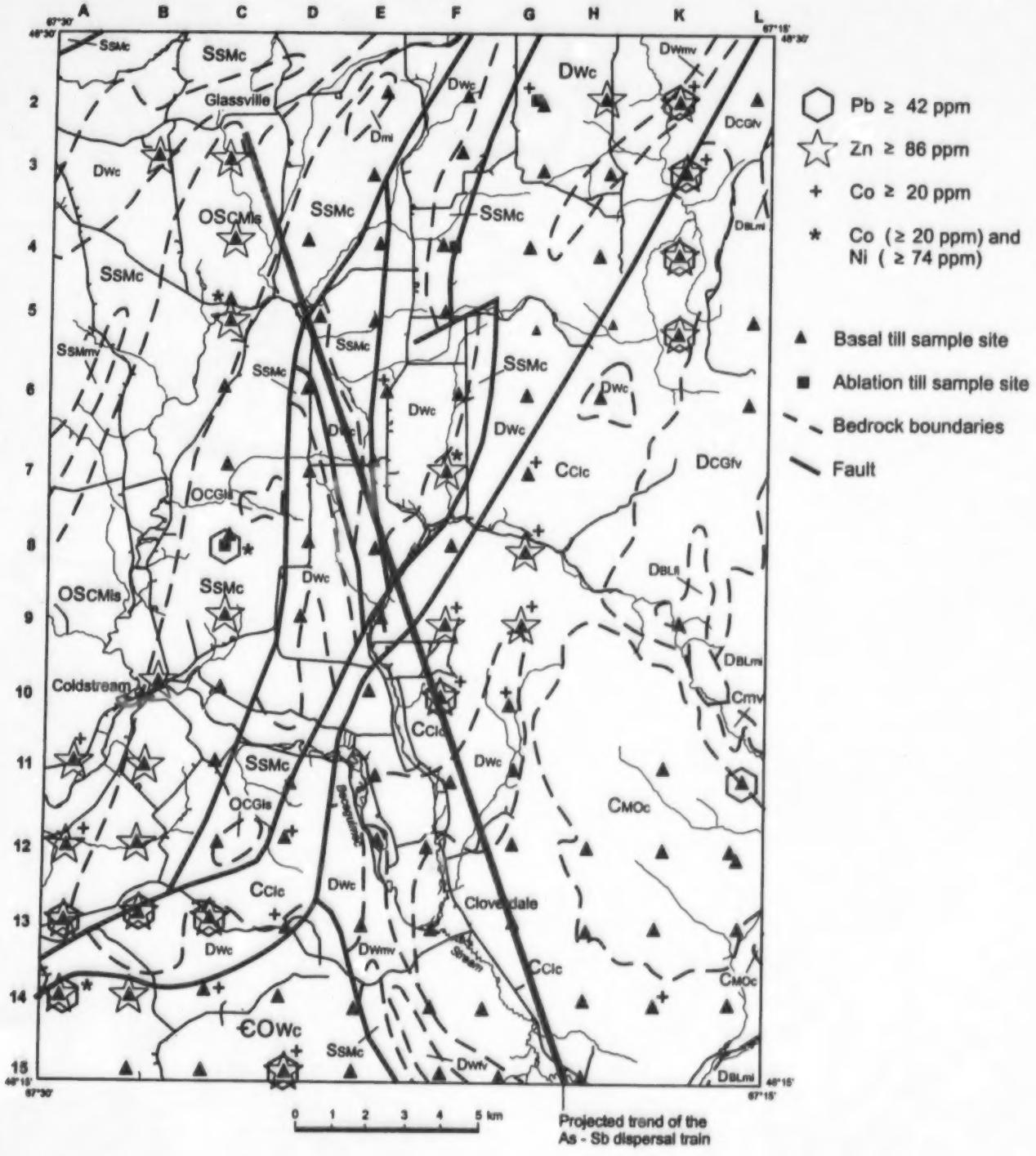

Figure 4. Bedrock geology, till sample site locations, and distribution of sites with elevated values for Pb, Zn, Co and Ni in the west half of the Coldstream map area.

Table 1. Table of Bedrock Formations, West Half of the Coldstream Map Area (NTS 21 J/06W)

System	Group	Formation	Map Unit	Lithology
Late Carboniferous	Pictou	Mountain View	CMOc	Grey quartzose sandstone and quartz-pebble conglomerate
Early Carboniferous	Mabou	Carlisle	CCIc	Red polymictic pebble-cobble conglomerate, red lithic sandstone; minor red mudstone locally containing limestone nodules; minor red breccia and grey arkose
		unnamed unit	Cmv	Dark grey, amygdaloidal mafic volcanic rocks
Devonian		unnamed unit	Dmi	Dark grey, fine-grained, diabasic gabbro; minor quartz-diorite
		Becaguimec Lake	DBLfi	Grey to pink, fine- to medium-grained, micrographic, biotite and hornblende–biotite granite and granodiorite; minor reddish brown quartz–feldspar porphyry and red granophyre
			DBLmi	Green to grey, medium-grained, diabase to ophitic gabbro; minor pinkish grey monzodiorite
	Tobique	Wapske	DWfv	Greyish green to pink felsic flows, tuff and breccia; minor quartz–feldspar porphyry
			DWmv	Dark green, amygdaloidal mafic volcanic rocks; minor sedimentary rocks
			DWc	Dark grey slate and siltstone interbedded with grey sandstone and grey pebble-cobble polymictic conglomerate
		Costigan Mountain	DCGfv	Pink trachytic feldspar porphyry, pink trachytic quartz–feldspar porphyry, pink lapilli rhyolite tuff; minor pink eutaxitic rhyolite tuff
Silurian	Perham	Smyrna Mills	SSMmv	Dark green, amygdaloidal, mafic volcanic rocks
			SSMc	Grey slate, green and grey siltstone and calcareous sandstone; minor red slate, grey graptolitic siltstone, green quartzose sandstone, orange-weathering, calcareous quartzose siltstone, grey lithic wacke and conglomerate, light grey limestone, and felsic volcanic rocks
Ordovician–Silurian	Matapedia	Carys Mills	OSCMls	Thinly interbedded light grey-weathering limestone and dark calcareous slate
Ordovician	Meductic	Craig Brook	OCGls	Interbedded grey to dark grey carbonaceous crystalline limestone, grey lithographic limestone, dark grey to black chert, and dark grey calcareous slate; minor quartzose sandstone, dolomite and light green sericitic tuff
Cambrian–Ordovician	Woodstock (Miramichi)		€OWc	Olive-green to grey quartzose wacke interbedded with grey–green and maroon slate

Surficial geology

Detailed (1:50 000 scale) surficial geology mapping of the Coldstream map area has not been conducted. However, Rampton and Paradis (1981) conducted reconnaissance mapping (1:250 000 scale) in the area, and Hunter and Lavergne (1982) mapped the surficial granular aggregate deposits at 1:50 000 scale. The results of these studies and earlier miscellaneous observations are summarized by Rampton *et al.* (1984).

Rampton and Paradis (1981) mapped the west half of the Coldstream map area as predominantly morainal veneer (till, generally discontinuous and less than 0.5 m thick over bedrock) or morainal blanket (till, generally 0.5 to 1.5 m thick and overlying bedrock). Hunter and Lavergne (1982) identify a number of comparatively small glaciofluvial deposits in this part of the map area. The greatest expanses of non-till deposits occur in parts of the Becaguimec Stream valley, where fluvial deposits (alluvium and glaciofluvial outwash) up to about 1 km in width have been mapped by Hunter and Lavergne (1982).

Observations made during the current study indicate that the till in the west half of the Coldstream map area is generally greater than 0.5 m thick. Therefore, according to the definition of Rampton and Paradis (1981), it occurs predominantly as a morainal blanket. Bedrock was encountered at the base of the till section at only 20% of the sampled sites, all at depths of 0.5 m or more. Thick till may be found locally in some of the valleys. For example, at site CS-B10 a large road cut exposes several metres of glaciofluvial sand and gravel overlying about 6 to 9 m of basal lodgement till.

Our observations indicate that the basal till in the study area is generally moderately compact to very compact. It is dominantly olive brown to yellowish brown in colour, except in the area overlying the Carlisle Formation where the colour is brown to reddish brown. Because of the variety of bedrock units in the west half of the Coldstream map area, the basal till exhibits a highly variable texture. Using the definitions of Folk (1968), basal till texture ranges from slightly gravelly sandy mud to silty sandy gravel, with gravelly sandy mud or sandy muddy gravel being the most common textures at the sample sites. Using the definitions of Canada Department of Agriculture (1974), the basal till varies from a clay to a very gravelly loamy sand, with gravelly to very gravelly loam being the most commonly observed texture. Pebble samples from the sites along the trend of the As–Sb dispersal train suggest that most of the pebble-sized material is of local origin, either very angular to subangular clasts derived from local bedrock units, or subrounded to rounded clasts reworked from local conglomerate units (primarily in the Carlisle Formation).

At the three sites where ablation till was sampled, the material was loose to moderately compact silty sandy gravel to gravel (very gravely sandy loam to very gravelly sand). Its colour was olive brown to yellowish brown.

TILL GEOCHEMISTRY

Previous studies

A reconnaissance geochemical survey of glacial deposits in west-central New Brunswick was conducted in 1983 by the Geological Survey of Canada (Kettles and Wyatt 1986), which included 18 sample sites in the west half of the Coldstream map area. Results were reported for the analysis of 14 elements (Ag, As, Cd, Co, Cr, Cu, Fe, Hg, Mo, Mn, Ni, Pb, U and Zn) in the clay fraction of the samples from 16 of these

sites (Kettles and Wyatt 1986). No results were reported for their sites 83KAR1448 and 83KAR1456.

Subsequently, a more extensive, multi-year (1985 to 1988) regional till geochemistry survey was carried out in the southern Miramichi Zone by the Geological Survey of Canada (Lamothe 1990, 1992). Sixty-six sites were sampled in the west half of the Coldstream map area during 1987 and 1988 (Lamothe 1990). In addition, the samples collected in 1983 were reanalysed, and analyses were obtained on the samples from the two sites for which no results were reported by Kettles and Wyatt (1986). Because the analyses were carried out over several years, the number of elements reported for each sample varied. Analytical results for As, Co, Cr, Cu, Fe, Mn, Ni and Zn were reported for all samples, obtained on clay fraction separates. Results for Ag, F, Hg, Mo, Na, Pb, Sn, U and W on clay fraction separates were reported for some of the samples. As, Au and Sb values, obtained on silt-plus-clay fraction separates, were reported for all samples collected in 1987 and 1988. Au and Sb values on the same size fraction were reported for all of the reanalysed 1983 samples, and As and Mo values were reported for all but one of these samples.

Kettles and Wyatt (1986) indicate that till was sampled at 12 of their sites, and glaciofluvial material was collected from the other six sites. Unfortunately, Lamothe (1990) does not indicate the nature of the sampled material in the second Geological Survey of Canada project. However, four of the sample sites (Geological Survey of Canada sites 87LFA8130, 87LFA8137, 87LFA8140 and 88LFA0121) lie within the limits of glaciofluvial deposits mapped by Hunter and Lavergne (1982). Another five of the sites (87LFA8123, 87LFA8132, 87LFA8133, 87LFA8145 and 87LFA8148) lie close to identified glaciofluvial deposits in stream valleys, and thus may be in glaciofluvial materials. In addition, five other sites were sampled within 1km of till sites sampled by Kettles and Wyatt (1986), presumably to confirm the results obtained by the earlier survey. Therefore, the effective average till sample density for the west half of the Coldstream map area based on the two Geological Survey of Canada projects was about one sample per 8 km^2. However, the samples in these two surveys were collected primarily along roads, and therefore the coverage of the area is irregular.

Lamothe (1992) interpreted the geochemical data presented in his earlier report (Lamothe 1990), and presented element distribution maps for Cu, Pb, Zn, Sn, W, U, Sb and Hg for the entire Miramichi Zone. A map indicating the locations of sites at which Au values were greater than 10 ppb was also included.

Determination of elevated values

In previous 1:50 000 scale till geochemistry studies in west-central New Brunswick, elevated values have been defined as including both anomalous and threshold anomalous values. Anomalous values were defined as those equal to or greater than four standard deviations above the mean value determined for the data obtained for the study area and subjected to a one step trimming process to remove extremely high values (e.g., Seaman 1998). Threshold anomalous values were defined as those equal to or greater than two standard deviations above the mean but less than the anomalous values.

In the text that follows, results quoted as anomalous were determined as noted above. However, for the purposes of this report, a different approach is used to define threshold levels. The major objective of this report is to identify the extent, in the Coldstream map area, of the As–Sb dispersal train previously identified in the adjacent Millville (NTS 21 J/03) map area (Seaman 1998). Therefore, to permit side by side comparison between the two map areas, the threshold values established for the west half of the

Millville map area (Seaman 1998) are, with one exception, used for the current study area. The exception is Pb. Pb values for most of the Coldstream samples exceed the 23 ppm threshold value established for the west half of the Millville map area. The samples from row 15 of the Coldstream area represent the same grid points as do the samples from row 1 of the west half of the Millville map area (Seaman 2001). However, the Pb values for the Coldstream samples average 1.8 times higher than those for the Millville samples. The reason for this discrepancy has yet to be identified: the Pb values obtained for the standard samples analysed with the samples from both areas fall within acceptable ranges. However, to compensate for this discrepancy, for this report the threshold value for Pb has been set at 42 ppm (=1.8 x 23 ppm). The appropriate threshold values for the other elements are indicated on Figures 2, 3 and 4.

The Cloverdale dispersal train

There appears to be a strong association between the area in the west half of the Coldstream map area underlain by the Carlisle Formation and the distribution of elevated values for As, Sb, Sn and W in till (Figures 2 and 3). In the study area the only anomalous values obtained for As (at site CS-G12, 104 ppm; and site CS-H13, 98.7 ppm and 91.0 ppm on duplicate samples), Sb (at site CS-F10, 5.3ppm; site CS-G12, 8.8 ppm; and site CS-H13, 5.0 ppm and 4.5 ppm on duplicate samples) and W (at site CS-L14, 8 ppm on each of two duplicate samples) were found in till samples from sites overlying this unit. Anomalous Au is also present in this area (at site CS-H14, 46 ppb and 40 ppb on duplicate samples). In addition, a sample of Carlisle Formation sandstone bedrock from site CS-GH14, along the projected trend of the previously identified dispersal train, contains detectable Au and elevated values for As and Sb. These results suggest that it is the Carlisle Formation itself that is mineralized. This mineralization could be either primary, in the form of palaeoplacer deposits, or secondary, resulting from replacement or diagenesis (Malcolm McLeod, personal communication, 2001).

All but one of the sites noted above with anomalous As or Sb values are in the vicinity of Cloverdale. Therefore, it is probable that it is the Carlisle Formation in the Cloverdale area that is the source of the As–Sb dispersal train that extends into the Millville map area.

Other areas with anomalous element concentrations

South Branch Southwest Miramichi River: Lamothe's (1992) figures illustrating the distribution of Pb and Zn in till samples from the Miramichi Zone outline a small area in the north-central part of the Coldstream map area with values above the 75th percentile level. The current sampling program confirmed the presence of elevated values for these two elements in this area (Figure 4). Elevated values for Pb and Zn occur in a north–south-trending belt in this part of the study area. Pb is anomalous at site CS-K02 (125 ppm) and in both field duplicate samples from site CS-K05 (83 and 80 ppm), and occurs above threshold levels at sites CS-K03 and CS–K04. Zn is anomalous at site CS-K02 (180 ppm by ICP analysis) and occurs above threshold levels at sites CS-H02, CS-K03, CS-K04 and CS-K05. Elevated As values are also present at all of the above sites. In addition, the samples from some of the sites exhibit elevated values for Co, Sb or Sn.

This belt of elevated As, Pb and Zn values extends from the Wapske Formation across the Howard Brook Fault and onto the Carlisle Formation. It is interpreted as most likely comprising a dispersal train from the area of the Salmon Brook and Foreston Ag, Cu, Pb and Zn occurrences (URNs 0260 and 0874,

respectively; Merlini 1999), approximately 6 km north-northwest of site CS-K02. While values for Cu in this dispersal train do not exceed the threshold level, the Cu value obtained for site CS-K02 (33 ppm) is approximately double that obtained for adjacent sites CS-H02 and CS-L02, indicating that locally elevated Cu values are associated with the dispersal train. Detectable Ag (0.3 to 0.5 ppm) is also associated with the sites in the dispersal train.

Lower Brighton–Little Pokiok Brook area: Elevated Pb values were obtained for three contiguous sites (CS-A13, CS-B13 and CS-C13) to the north of Little Pokiok Brook in the southwest corner of the Coldstream map area, and for the lower, more locally derived, till at site CS-A14 near Lower Brighton. These sites lie close to east–west-trending elements of the Woodstock Fault system, suggesting that the elevated Pb values may reflect mineralization associated with the fault system. In addition to having elevated values of Pb, the lower till at site CS-A14 is anomalous in Co (47 ppm) and Mo (5 ppm, by both ICP and INAA), and returned elevated values for As, Hg, Sb, Sn and Zn. Again, a local source of mineralization is indicated.

An extensive area of elevated Zn values encompasses the above four sites and includes several neighbouring sites (Figure 4). The distribution of sites with elevated Zn values suggests that the Carys Mills Formation in the study area may contain high background levels of Zn. However, completion of sampling in the western part of the map area will be required to determine whether the elevated Zn values in the Lower Brighton–Little Pokiok Brook area and in the Glassville area to the north form part of a continuous belt.

East Brighton–Pole Hill area: Elevated values for Au were obtained for sites MV-C01 and MV-D01 in the Millville map area (Seaman 1998), to the south of the Lower Brighton–Pole Hill area in the southwestern corner of the current study area. Elevated values of As, Co, Hg, Ni and Pb were also obtained for site MV-C01.

Non-detectable Au values were obtained for the samples from sites CS-C15 and CS-D15, the Coldstream map area sites that correspond to the above Millville area sites (Seaman 2001). However, an elevated value for Au was obtained for site CS-C14, and Au was anomalous at site CS-D14 (43 ppb). Elevated values for As, Sb, Sn or W are also found in this vicinity (sites CS-C13, CS-D13 and CS-D15). All of these sites lie down-ice of an area of Carlisle Formation rocks lying between the Knowlesville and Howard Brook faults. Given the above noted association between these elements and the Carlisle Formation, it seems probable that it comprises the source for these elevated values.

Elevated values of Co, Pb and Zn are associated with some of the above sites (Co is anomalous at site CS-D15, 41 ppm). These elevated values were probably derived from the same source as noted above for the Lower Brighton–Little Pokiok Brook area.

Hg, and the Woodstock Fault system: Lamothe's (1992) figure for the distribution of Hg in the Miramichi Zone indicates a site in the study area with a value in the greater than 98th percentile range. This is Geological Survey of Canada site 87LFA8046, which lies along the trend of the Knowlesville Fault, for which duplicate samples of the clay fraction gave values of 420 and 460 ppb Hg (Lamothe 1990). The highest value for Hg obtained in the current survey was 187 ppb on the silt-plus-clay fraction from site CS-F09, which is close to the Howard Brook Fault. The distribution of elevated Hg values (Figure 2) suggests a general correlation with various splays of the Woodstock Fault system.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

1. The dominant glacial unit in the west half of the Coldstream (NTS 21 J/06) map area is a blanket of basal till generally greater than 0.5 m thick. This till is highly variable in texture and colour, representing the variability in the bedrock units that underlie the area. The lithology of the pebble fraction suggests that the till is dominantly of local derivation.

2. Mineralization in the Carlisle Formation in the Cloverdale area is most probably the source of the Cloverdale As–Sb dispersal train. Bedrock geology and geochemistry investigation of the Carlisle Formation are recommended to confirm that it is indeed mineralized, to determine the nature of the mineralization, and to identify whether economic concentrations are present.

3. A belt of elevated As, Pb and Zn values occurs in the northeastern part of the study area. This belt is most likely a dispersal train from the Salmon Brook and Foreston mineral occurrences in the southern part of the neighbouring Juniper (NTS 21 J/11) map area. Sampling in the Juniper map area will be required to confirm this interpretation.

4. Elevated values for Pb and a number of other elements were found in the samples from the southwestern corner of the Coldstream map area. A number of the sites with elevated values lie along the trend of the Woodstock Fault system, which suggests that there may be local mineralization associated with the fault. Other sites lie to the southeast of a fault-bounded wedge of the Carlisle Formation, which suggests that the elevated values at these sites may be due to dispersal from mineralization in this formation.

5. Elevated Hg values were obtained for a number of sample sites that are spatially associated with splays of the Woodstock Fault system.

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The figures for this report were prepared by Terry Leonard. The paper was critically reviewed by Toon Pronk, and approved for publication by Les Fyffe, Manager of Geological Surveys South.

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THE NINE MILE BROOK (WILLETT) MASSIVE SULPHIDE OCCURRENCE, BATHURST MINING CAMP, NEW BRUNSWICK (NTS 21 O/08E) †

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WALKER, J.A. 2001. The Nine Mile Brook (Willett) massive sulphide occurrence, Bathurst Mining Camp, New Brunswick (NTS 21 O/08E). *In* Current Research 2000. *Edited by* B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 2001-4, pp. 111–133.

The Nine Mile Brook (Willett) Zn–Cu–Pb occurrence comprises a high-grade massive sulphide lens that has an east-west strike length of 10 m, and a thickness of approximately 1 m. The lens is vertical to steeply north-dipping and extends down-dip less than 30 m.

The sulphide lens occurs in highly deformed and dismembered sedimentary rocks of the Boucher Brook Formation, close to their tectonic contact with mafic volcanic rocks of the Canoe Landing Lake Formation. In addition to the main sulphide lens, smaller blocks and stringers of sulphides occur immediately above, and along strike from, the main lens. Blocks of feldspar-porphyritic rhyolite (2 cm to 10 m in long direction), which are texturally and chemically similar to the Spruce Lake Formation, occur in a narrow zone along strike from the sulphide lens. The felsic volcanic rocks show evidence of strong hydrothermal alteration, whereas the tectonized sedimentary host rocks show no such alteration.

La venue de Zn–Cu–Pb du ruisseau Nine Mile (Willett) abrite une lentille de sulfures massifs à forte teneur d'une longueur de dixmètres et d'une épaisseur d'environ un mètre dans un axe est-ouest. La lentille varie d'un angle vertical à une inclinaison prononcée vers le nord et elle s'étend en aval-pendage sur moins de 30mètres.

La lentille de sulfures se trouve dans des roches sédimentaires largement déformées et démembrées de la Formation de Boucher Brook, à proximité de leur surface de contact avec des roches volcanomafiques de la Formation de Canoe Landing Lake. Outre la lentille principale de sulfures, des veinules et des massifs plus petits de sulfures sont présents immédiatement au-dessus ainsi que le long de l'axe du corps, à partir de la lentille principale. Des massifs de rhyolite feldspatho-porphyrique (de deux à dix centimètres dans la direction de la longueur) ayant une texture et une composition chimique semblables à celles de la Formation de Spruce Lake occupent une zone étroite longeant l'axe du corps depuis la lentille de sulfures. Les roches volcanofelsiques présentent des signes d'altération hydrothermale marquée, tandis que les roches hôtes sédimentaires tectonisées n'affichent aucune altération.

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† New Brunswick Geological Surveys Branch ordinary budget.

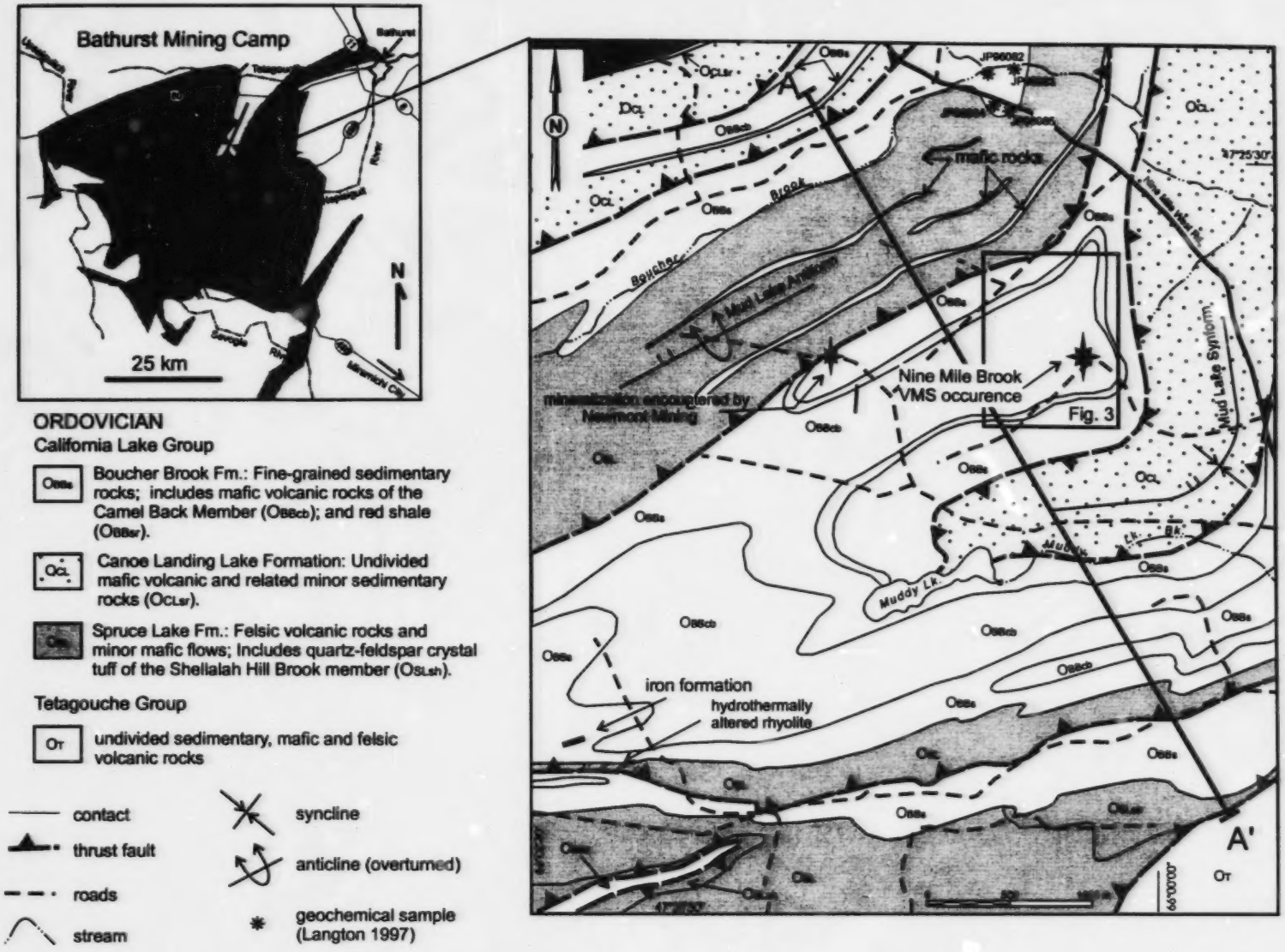

Figure 1. Location map showing the position of the Nine Mile Brook massive sulphide occurrence (URN 287) with respect to the Bathurst Mining Camp and the Brunswick No. 12 mine. Geology is modified from van Staal and Rogers (2000a, 2000b). Profile along line of section A–A' is presented in Figure 6. Abbreviation: VMS – volcanogenic massive sulphides.

INTRODUCTION

The Nine Mile Brook Zn–Cu–Pb massive-sulphide occurrence (Mineral Occurrence Database Unique Record Number [URN] 0287) is hosted by polydeformed Middle Ordovician sedimentary rocks of the Bathurst Supergroup (Figure 1). The original discovery, comprising several high-grade, massive-sulphide boulders (approx. 1 m diameter), was made by C.A. Willett in 1975 (Figure 2). Several companies have conducted work in and around the Nine Mile Brook occurrence since its discovery but only the three most important projects and their results are summarized in the section on previous work.

This study was undertaken in order to better understand the setting of the Nine Mile Brook occurrence with respect to regional tectonostratigraphy and, if possible, the paleoenvironmental and alteration controls on sulphide deposition. The work involved relogging drill core, lithogeochemical analysis, compilation of assessment data and geologic mapping. The results of this work are described herein.

LOCATION AND ACCESS

The Nine Mile Brook occurrence is located approximately 37.5 km south-southwest of Bathurst and 12.5 km southwest of Noranda Inc.'s No. 12 mine. The area is easily accessed via Highway 430 south from Brunswick Mines, and the Nine Mile Brook West haulage road (Figure 1).

Outcrops are sparse except for exposures in trenches, on roads, and in bulldozed areas. Consequently, this study relied heavily on drill core to obtain material for petrologic and geochemical analyses.

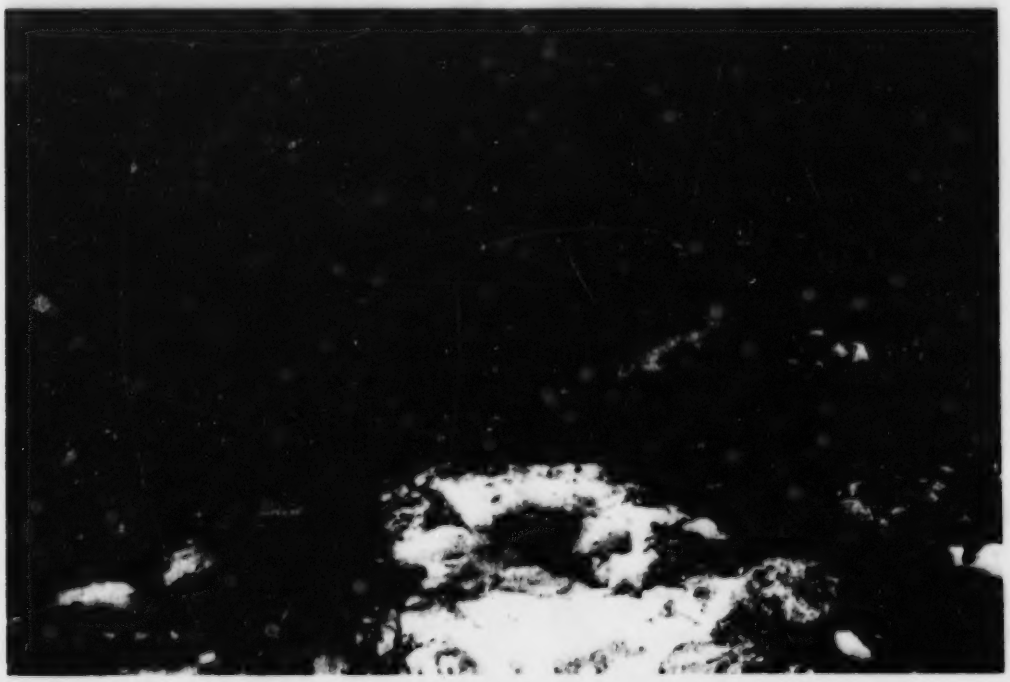

Figure 2. Massive sulphide boulders (approx. 1 m in diameter) at the Nine Mile Brook massive sulphide occurrence.

PREVIOUS WORK

After the initial discovery in 1975, the property was optioned by Newmont Mining Corp. of Canada Ltd. (Price Co. Ltd. 1976a, 1976b), which carried out geophysical surveys, trenching and diamond drilling. The first hole drilled (76W-1) was collared in massive sulphides but it was unclear as to whether or not this was float. In addition to 76W-1, ten other holes were drilled by Newmont Mining in and around the area, but the location of a bedrock source for the mineralized boulders was not determined. Newmont Mining also encountered some minor mineralization and alteration approximately 1500 m west of the main showing (Figure 1). Although none of the Newmont drill holes intersected massive sulphide mineralization, clasts and minor disseminated sulphides were intersected in a few holes.

The property was optioned to Freewest Resources Canada Ltd. in 1994–95; a program of geophysical surveys, trenching and diamond drilling (15 holes) was conducted. Extensive trenching and overburden stripping in the vicinity of the original boulder discovery succeeded in locating a bedrock source for the massive-sulphide boulders as well as a second sulphide occurrence north of the main showing (Cavalero 1995; Mersereau 1995). The drilling was not filed for assessment credit; rather, the first seven are listed in a report for the New Brunswick Exploration Assistance Programme under Report No. NBEAP-022, whereas the remaining eight drill logs have not been officially filed.

Most recently, the property was optioned by Inmet Mining Corporation, which undertook a trenching program, ground geophysical surveys including deep penetrating induced polarization (IP), and diamond drilling [4 holes: WL-01 through WL-04] (Clark 1997; MacDonald 1997). This work failed to extend the known mineralization or uncover new occurrences. All of the drill cores recovered by Freewest Resources and Inmet Mining, and some of the Newmont Mining drill cores, are stored at the provincial drill core library at Madran.

REGIONAL GEOLOGY

The Bathurst Mining Camp is a polydeformed Middle Ordovician sequence of bimodal volcanic and intercalated sedimentary rocks deposited in a back-arc basin that formed on siliciclastic rocks (flysch sequence) of a stable continental margin (van Staal and Fyffe 1991). During closure of the back-arc basin in the late Ordovician to Early Silurian these rocks were dismembered and deformed in a subduction-related accretionary prism. Recent work indicates that the rocks in the Bathurst Mining Camp can be subdivided into five groups, namely: Miramichi, Sheephouse Brook, Tetagouche, California Lake and Fournier groups. See Wilson *et al.* (1998) and Thomas *et al.* (2000) for detailed descriptions.

Structurally, the Bathurst Mining Camp is highly complex; it has been divided into four major thrust nappes that internally contain numerous stratigraphic cutouts and/or repetitions related to subsidiary thrust faults. At least five generations of folds have been recognized (McCutcheon *et al.* 1993).

The rocks in the vicinity of the Nine Mile Brook occurrence belong to the California Lake Group (van Staal and Rogers 2000a, 2000b). Regionally, the California Lake Group comprises three volcanic-dominated, thrust-bound nappes, two of which are represented in Figure 1. The structurally highest Nappe contains rocks assigned to the Canoe Landing Lake Formation and overlying Boucher Brook Formation. These rocks occupy the core of the Mud Lake Synform and extend from south of the occurrence, where they strike east–west, to east of the showing where they have a north–south strike (Figures 1 and 3).

In the vicinity of the occurrence, the Canoe Landing Lake Formation (unit OCL on Figure 1) comprises massive to pillowed tholeiitic basalt interlayered with basaltic tuffs and related fragmental and epiclastic rocks. This unit also includes minor green to light grey, massive to banded chert, red cherty hematite–magnetite iron formation, and black, argillaceous magnetite iron formation.

The Boucher Brook Formation (Units OBBsp and OBBsg on Figure 1) hosts sulphide mineralization at the Nine Mile Brook occurrence and is the areally most extensive unit in the study area (Figure 1). It comprises dark grey to black, thin-bedded shale interstratified with thin to thick beds of green to black, quartz-rich and/or feldspathic sandstone. Minor interbedded alkalic basalt, assigned to the Camel Back Member (unit OBBcb on Figure 1), lies immediately north and to the west of the occurrence (Figure 1).

The type section of the Boucher Brook Formation lies north of the occurrence, on the north limb of the Nine Mile Synform and comprises a sequence of dark grey to black siltstone and interbedded wacke that rests conformably on felsic volcanic rocks of the Spruce Lake Formation.

Approximately 4 km southwest of the occurrence, a magnetite iron formation (approx. 1.5 m in thickness) occurs in sedimentary rocks less than 200 m above a presumed conformable contact with strongly altered felsic volcanic rocks of the Spruce Lake Formation (Figure 1). The relationship, if any, between this iron formation and the Nine Mile Brook occurrence is unknown.

The Canoe Landing Lake nappe is structurally overlain by the Spruce Lake Nappe, which is the most extensive in the study area and contains the Nine Mile Brook occurrence (Figures 1 and 3). The stratigraphic succession within this nappe consists of Spruce Lake Formation and overlying Boucher Brook Formation (Figure 1). The Spruce Lake Formation (unit OSL on Figure 1) comprises aphyric- to feldspar-phyric rhyolite as well as associated sedimentary and minor mafic volcanic rocks. Locally, the base of the Spruce Lake Formation consists of quartz–feldspar crystal tuff that has been assigned to the Shellalah Hill Brook Member. Regional structural interpretation by van Staal (1994) and van Staal and Rogers (2000a, 2000b) places the Nine Mile Brook occurrence on the north limb of the Mud Lake Synform, an F_2 structure that is refolded to the west by the Nine Mile Synform, an F_4 structure (Figure 1).

Several volcanogenic massive sulphide (VMS) deposits occur in this nappe, the economically most important being the Caribou deposit that is a resource of approximately 70 000 000 t grading 0.5% Cu, 1.6% Pb, 4.3% Zn, 51.3 g/t Ag and 1.715 g/t Au (Thomas *et al.* 2000 and references therein).

DEPOSIT STRATIGRAPHY

The area in the vicinity of the occurrence was mapped in detail by Cavalero (1995), the results of which are included in Figure 3. Three formations are represented in the map area and are described below.

Canoe Landing Lake Formation

This unit (OCL on Figure 3) mainly comprises massive to pillowed basalt flows that underlie an area to the southeast of the occurrence.

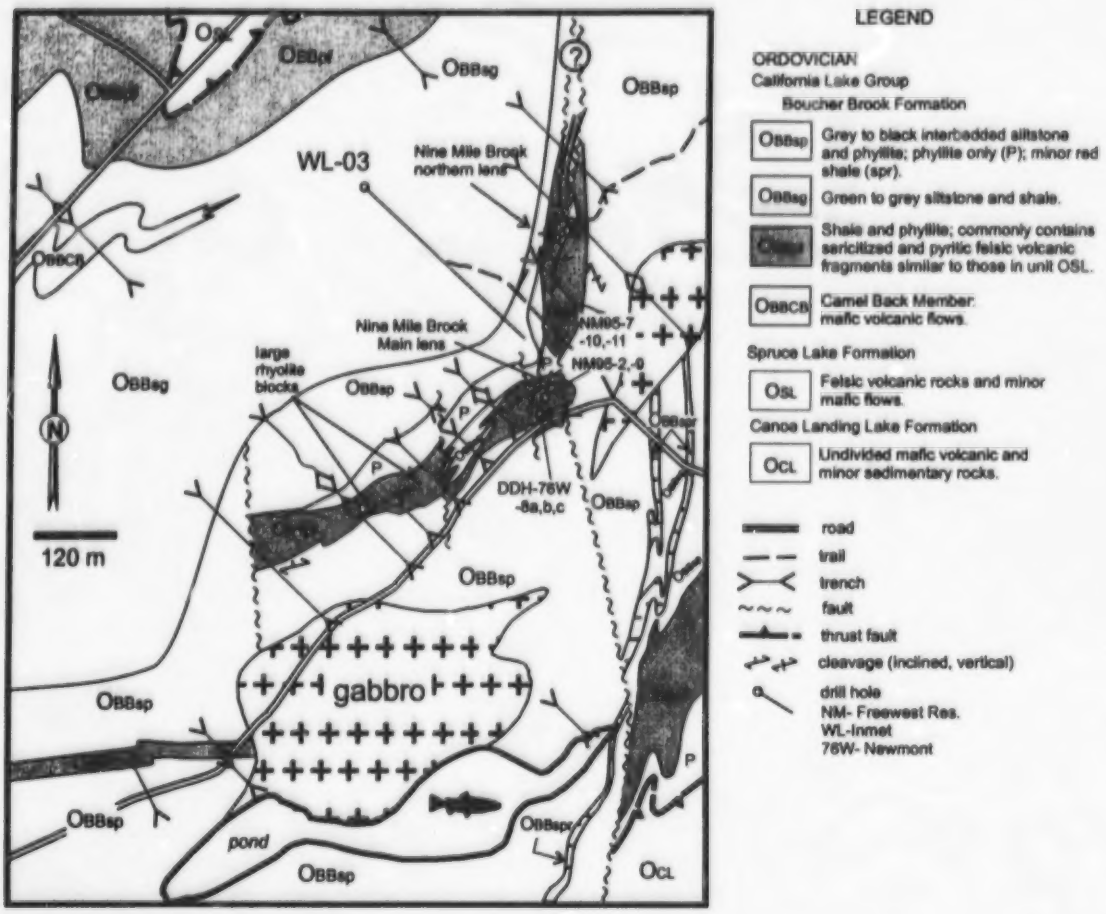

Figure 3. Detailed geology of the Nine Mile Brook volcanogenic massive sulphide occurrence. Geology is modified from Cavalero (1995) and shows trench locations. Some of the diamond-drill holes are also shown. See Figure 1 for location.

Boucher Brook Formation

At the Nine Mile Brook occurrence, the Boucher Brook Formation is divided into four subunits (Figure 3). The stratigraphic relationship between these subunits is unknown.

Unit OBBsp is an interlayered sequence of dark grey to black siltstone and shale that locally includes minor red shale. This subunit hosts the massive sulphide mineralization of the Nine Mile Brook occurrence and is highly deformed (Figure 4a and 4b).

Unit OBBpf is a variant of unit OBBsp that contains blocks of sericitized and pyritized felsic volcanic material, similar to rocks in the Spruce Lake Formation, in addition to shale and phyllite.

Unit OBBsp grades northward (stratigraphically up?) into green to grey siltstone and wacke (Unit OBBsg in Figure 3, and Figure 4c). To the southwest and, to a lesser extent, north of the occurrence, there are several exposures of pillowed to massive basalt flows interlayered with the sedimentary sequence. Mafic flows intercalated with sedimentary rocks of the Boucher Brook Formation are assigned to the Camel Back Member although they are far less abundant than suggested by van Staal and Rogers 2000a; see Figure 1). The red shale (Unit OBBspr) on Figure 3, located immediately east and south of the showing, was included in the Camel Back Member by van Staal and Rogers (2000a). However, the lack of associated basalt and the presence of rhyolite (Unit OBBpf) suggest that this is a tectonically disrupted zone similar to that hosting the Nine Mile Brook occurrence. Consequently, assignment of these rocks to other than the Boucher Brook Formation would be tenuous.

Spruce Lake Formation

The Spruce Lake Formation (Unit OSL on Figure 3) comprises sericitized and pyritized feldspar-phyric felsic volcanic rocks in the northern part of the map area. The felsic volcanic rocks in unit OBBpf, described above, are considered exotic blocks of the Spruce Lake Formation, and occur intermittently along strike from the occurrence to the west and to the north (Cavalero 1995). These blocks are too small to portray at the scale of regional mapping (Figure 1).

The felsic rocks, which comprise variably altered and mineralized aphyric to feldspar-phyric rhyodacite, occur as isolated blocks in a sedimentary mélange (Unit OBBpf on Figure 3). The blocks range in size from a few centimetres to more than 10 m, and are aligned parallel top the dominant cleavage (Figure 5a, 5b and 5c). Similar rocks, cropping out north of the occurrence in the Mud Lake Antiform (Figure 1), have been assigned to the Spruce Lake Formation.

Approximately 4 km southwest of the occurrence (Figure 1), in the vicinity of the iron formation discussed above, felsic volcanic rocks of the Spruce Lake Formation are strongly altered immediately adjacent to their contact with overlying Boucher Brook sedimentary rocks. However, there is no evidence of alteration or mineralization in the sedimentary rocks above the contact, despite the presence of iron formation.

Late intrusions

Two mafic intrusions crop out immediately south of the occurrence (Figure 3). They are coarse-grained, equigranular to subophitic gabbro and have no anomalous magnetic response. These intrusions post-date both the Boucher Brook and Canoe Landing Lake formations as shown by cross-cutting relationships and lack of penetrative fabric.

In addition to the formations and intrusions described above, two zones of mélange, consisting of disrupted or dismembered sedimentary fragments in a sedimentary matrix and including locally abundant felsic volcanic fragments, were delineated by detailed mapping. These are interpreted to represent tectonic mélange that formed during thrust faulting. This mélange also contains the massive sulphides of the main and northeast zones (see below).

A geological cross section, showing the tectonostratigraphic relationships in the study area, is presented in Figure 6.

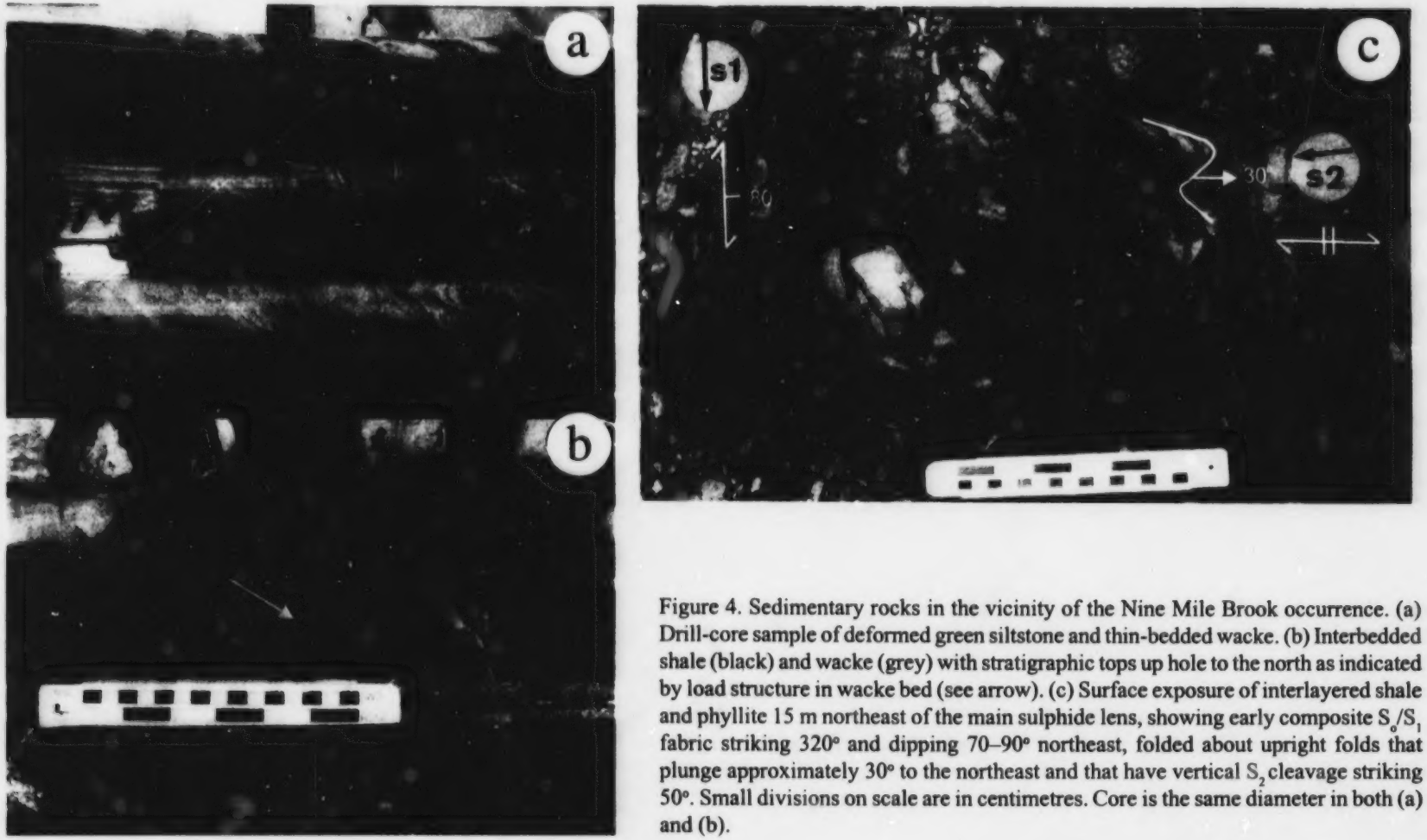

Figure 4. Sedimentary rocks in the vicinity of the Nine Mile Brook occurrence. (a) Drill-core sample of deformed green siltstone and thin-bedded wacke. (b) Interbedded shale (black) and wacke (grey) with stratigraphic tops up hole to the north as indicated by load structure in wacke bed (see arrow). (c) Surface exposure of interlayered shale and phyllite 15 m northeast of the main sulphide lens, showing early composite S_o/S_1 fabric striking 320° and dipping 70–90° northeast, folded about upright folds that plunge approximately 30° to the northeast and that have vertical S_2 cleavage striking 50°. Small divisions on scale are in centimetres. Core is the same diameter in both (a) and (b).

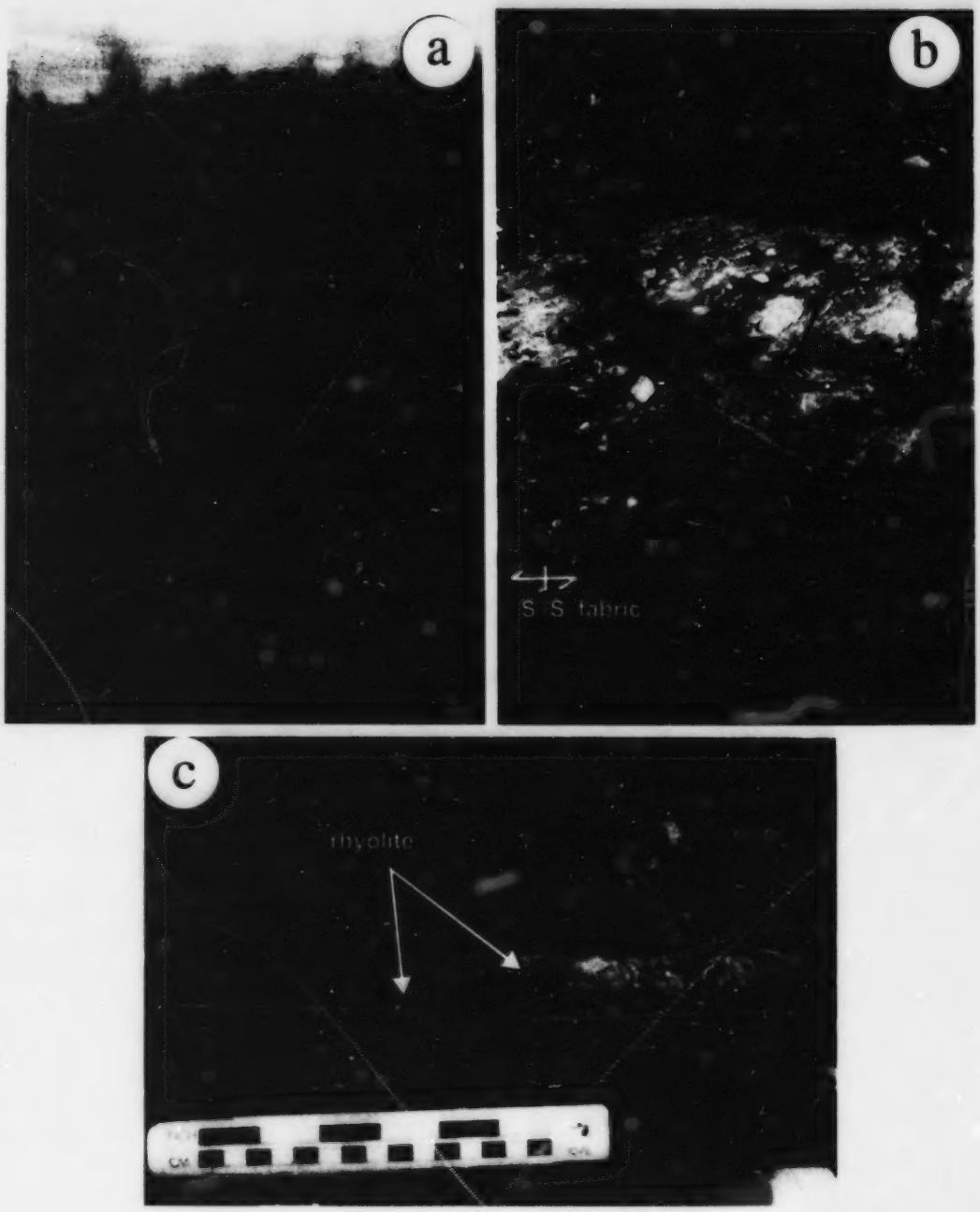

Figure 5. Rhyolite blocks in the tectonic mélange at the Nine Mile Brook occurrence. (a) Large hydrothermally altered rhyolite block more than 10 m in length and approximately 1.5 m in width. The view is to the east with the block oriented at 080° parallel to S_2 and late northeast-trending sinistral offsets at 020°. The block is alligned parallel to the main regional structure and is part of unit OBBpf in Figure 3. The Willett sulphide body crops out in the background. (b) Close-up of a rhyolite block; looking north. Note the northeast-trending fault off-setting rhyolite and black shale on the margins of the block. The cleavage symbol is alligned parallel to the main structural fabric. The compass at the bottom left is 17 cm in long dimension. (c) Drill core showing porphyritic rhyolite fragments in a shale mélange matrix. Small divisions on the scale are in centimetres.

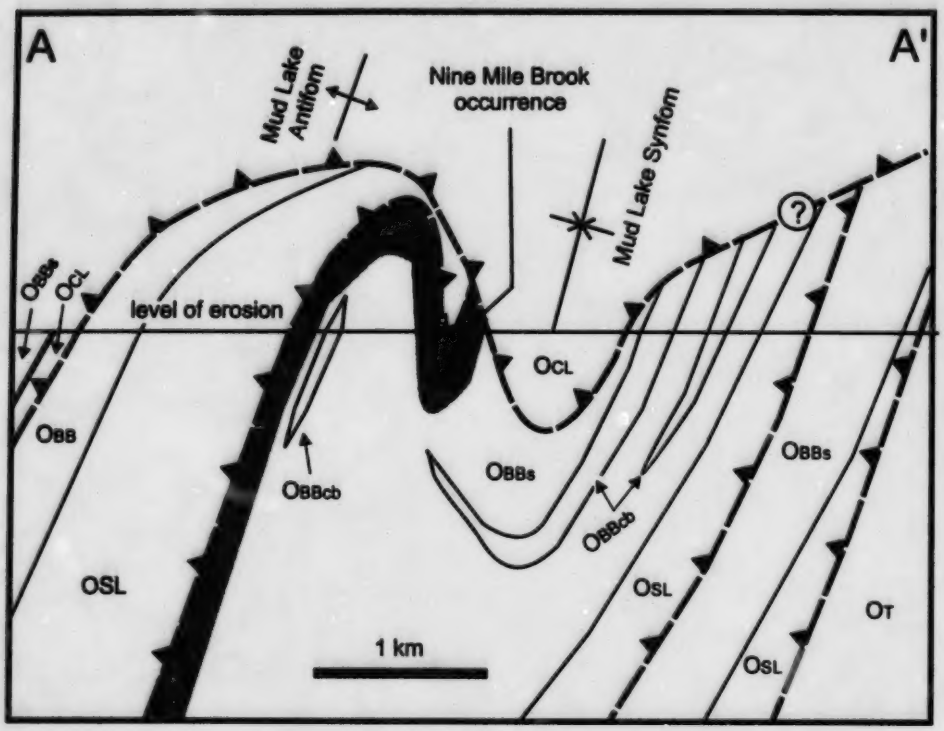

Figure 6. Geological cross section through the Nine Mile Brook area. Line of section A–A' is located on Figure 1. Unit abbreviations are the same as in Figure 1.

MINERALIZATION

Mineralization occurs in three locations on the property. The largest exposure of stratiform (?) volcanogenic-massive-sulphide-type mineralization in the area occurs in the main trench, i.e., the main zone, and comprises a more or less east–west-striking lens of massive sulphides approximately 10 m long and 1 m thick (Figure 7a). The lens is moderately folded about a north–south axis and dips steeply to the north. Several north–south-trending minor faults offset the lens. The sulphide lens is mineralogically zoned with sphalerite and lesser amounts of galena concentrated on the north side (top) and chalcopyrite concentrated on the south (bottom). The Zn-rich top is generally layered (Figure 7b), whereas the Cu zone is represented by irregular chalcopyrite masses at the base of the massive lens, or as stringers with pyrite below the massive lens (Figure 7c). Cavalero (1995) reports the following chip sample assays from three zones, listed in ascending stratigraphic order, from the main zone.

Zone	Cu (%)	Pb (%)	Zn (%)	Ag (oz./ton)	Au (oz./ton)
Cu	16.20	3.44	0.12	6.21	0.016
Cu–Zn	8.4	1.96	4.90	2.28	0.060
Zn	0.39	1.32	14.70	1.49	0.118

An analysis of the massive sulphide from this zone (McClenaghan, in prep.; Table 1) shows that it is typical of volcanogenic massive sulphide mineralization in the Bathurst Mining Camp (i.e., elevated Cd, As, Sb, etc.). The lens at the main zone has metal ratios that are atypical of Bathurst Mining Camp massive sulphide deposits. Specifically, the Nine Mile Brook occurrence is Zn–Cu-rich and contains very little Pb, whereas other deposits in the camp tend to be Zn–Pb rich with significant Cu grades restricted to stringer zones.

The upper (northern) contact shows evidence of sulphide remobilization and recrystallization and forms an angle of approximately 70° to the primary sulphide layering that parallels the core axis, indicating a possible tectonic cut-out (Figure 7b). The lower (south side) of the massive lens is gradational into stringer zone mineralization and thence into felsic volcanic rocks that are variably pyritic and altered (Figure 7c). The mineralized zone has an abrupt lower contact with unmineralized sedimentary mélange. The footwall rocks to the massive sulphide lens are grey to black shale, locally phyllitic, containing allochthonous blocks (5 cm to 10 m in long direction) of pyritized rhyolite and fragments of wacke and slate. Locally, this unit displays evidence of intense folding and transposition of primary layering. The largest blocks of rhyolite constitute mappable units at 1:2400 scale.

The hanging wall comprises dark grey shale and locally siliceous phyllite. Clasts of pyritized rhyolite, similar to those in the footwall, are also present. There is no obvious difference between the sedimentary rocks in the immediate footwall and hanging wall.

A second exposure of sulphides comprises a weathered "sulphide sand" that crops out approximately 220 m north of the main zone. This lens was trenched and drilled by Newmont Mining Corp. of Canada Ltd. (Price Co. Ltd. 1976a, 1976b). Later, Freewest Resources Canada Ltd. trenched and drilled six holes, some of which intersected sulphide mineralization similar in width to the main zone. This lens displays the same metal zonation as the main zone except that the inferred top is to the east (i.e., opposite that in the main zone). The reversal in facing direction could be explained by an anticlinal axis between the two zones. Alternatively, if the sulphide lenses are within a mélange, the facing direction may be random, as massive sulphides act as rigid bodies that rotate in a sedimentary matrix.

Both the main and north zones were intersected in holes drilled by Freewest in 1994–95. Unfortunately, attempts to increase the strike length or the down-dip extension of these sulphide lenses failed.

Approximately 1500 m west of the main zone, several trenches excavated by Newmont and reopened by Freewest revealed an east-northeast-striking mineralized horizon. This area was drill tested by two Newmont holes. Although only minor pyrite mineralization was encountered, altered felsic volcanic rocks similar to those in the main zone are present here as well.

STRUCTURE

There is evidence for at least three phases of deformation in the vicinity of the Nine Mile Brook occurrence.

The earliest deformation resulted in the development of a strong layer-parallel cleavage (S_0/S_1) that has an average strike of 080° in the west and 030° in the northeast (Figure 4c). This fabric is interpreted to have developed in conjunction with Late Ordovician to Early Silurian D_1 thrust faulting (McCutcheon *et al.* 1993).

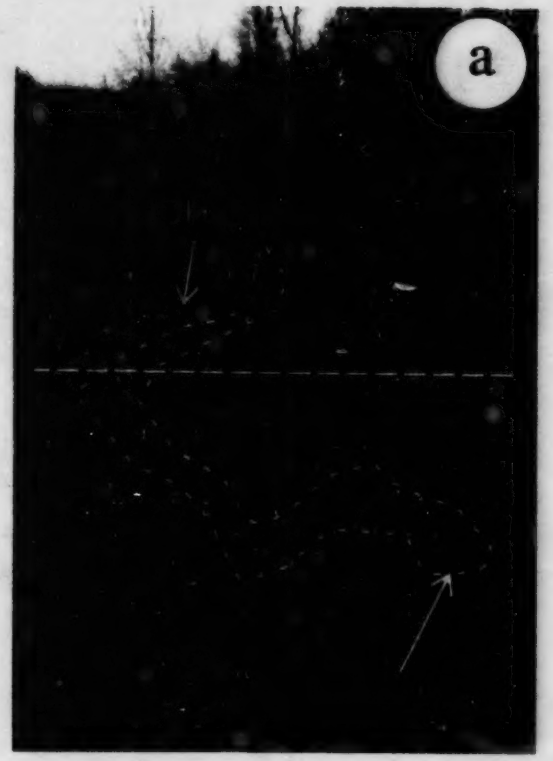

Figure 7. Massive sulphide textures from the Nine Mile Brook volcanogenic massive sulphide occurrence. (a) Surface photograph of the Nine Mile Brook occurrence, looking west-northwest. Note north–south fault (left to right in the photograph) through axis of fold. The lens is approximately 1 m wide. (b) Top of massive lens showing upper contact at 45° to core axis, parallel to S_2 foliation. Note S_0 primary layering parallel to the core axis; from drill hole NM95-5. (c) Chalcopyrite–pyrrhotite stringer-type mineralization at the base of the lens; from drill hole NM95-5.

A later event re-orients S_0/S_1 about tight to isoclinal, doubly plunging, east–west-trending folds (i.e., the Mud Lake Synform and Mud Lake Antiform). These later folds have an associated axial planar cleavage that strikes approximately 050° (Figure 4c). F_4 folding (e.g., Nine Mile Lake Synform on Figure 1) rotated $S_0/S_1/S_2$ at the Nine Mile Brook showing from an east-northeast to a north–south orientation (Figure 3).

Two sets of faults are recognized at the Nine Mile Brook occurrence. The early set comprises thrust-related deformation zones. The Nine Mile Brook sulphide lens lies on the west side of a large north-northeast-striking deformation zone that appears to dip steeply toward the north (Figure 3). A second set comprises late, north-northeast-striking, sinistral, brittle faults offset all map units, including the massive sulphide lens and the larger rhyolite blocks in the mélange to the west of the surface exposure of the sulphide lens (Figures 3 and 5a, 5b). The sulphide lens is cut by at least two dextral faults that strike roughly north–south (Figure 7a). Immediately east of the main lens, this fault set is subparallel to strike, and offsets in units are less obvious. The faults are thought to have formed as a result of syn- to post-F_4 deformation (McCutcheon *et al.* 1993).

LITHOGEOCHEMISTRY

A small suite of samples of representative felsic volcanic (n=4) and sedimentary (n=3) rocks from the vicinity of the main trench was collected from drill core (Tables 1 and 2). Analyses were carried out by Actlabs; the analytical methods and detection limits are reported in Tables 1 and 2. Samples are listed by drill hole number, followed by the down-hole depth in metres. Like most rocks in the Bathurst Mining Camp, hydrothermal alteration and metamorphism have rendered major-element chemistry of little use in petrogenetic discrimination. Consequently, much reliance is placed on the high-field-strength elements (Al, Ti, Y, Th, Zr, Nb, and heavy-rare-earth elements), which are relatively immobile during regional metamorphism and hydrothermal alteration (Lentz and Goodfellow 1992).

Felsic volcanic rocks

On a Zr/TiO_2 versus Nb/Y diagram, the Nine Mile Brook samples fall within the rhyodacite/dacite field (Figure 8a). With the exception of the Nepisiguit Falls Formation, these rocks are slightly less evolved than expected for Bathurst Mining Camp felsic volcanic rocks, which plot mainly in the upper part of the rhyodacite/dacite field and in the rhyolite field. This is probably a function of the apparent increase in TiO_2 resulting from mass loss due to hydrothermal alteration.

Several samples of rhyolitic (?) rocks were collected from Freewest' diamond-drill holes 95-7, -8 and -14 that intersected the main zone. As is evident from the very high Al_2O_3 (up to 21 wt. %) and TiO_2 (0.28–0.89 wt. %) and low SiO_2 contents, there has been significant mass loss due to alteration in these rocks. Total Fe, in the form of Fe_2O_3, is also enriched and is manifested by abundant pyrite in the samples. However, unaltered porphyritic rocks from the Nepisiguit Falls Formation in the footwall of the Brunswick No. 6 deposit have TiO_2 values in the range of 0.5 to 0.6 wt. %.

The Zr/Y ratio for these samples is low relative to other felsic units in the Bathurst Mining Camp. The majority of the felsic samples collected from the Nine Mile Brook occurrence have Zr/Y values less than 4.3, similar to values obtained from Spruce Lake Formation in other parts of the camp (Rogers and van Staal 1996). Other felsic units in the camp (i.e., Nepisiguit Falls and Flat Landing Brook formations of the Tetagouche Group) have Zr/Y values greater than 4.3 (Figure 8b).

Table 1. Lithogeochemical Analyses of Felsic Volcanic Rocks and Massive Sulphides Collected from Drill Core at the Nine Mile Brook Massive Sulphide Occurrence

Sample Name Rock Type	Method (detection limit)	95-7-12.3 porphyritic rhyolite	95-7-32.3 felsic volcanic	95-14-88.5 qtz-phyric rhyolite	95-8-87.8 felsic volcanic	95-8-53 porphyry	Avg. Rhyolite (this study)	NM 95-4-84.8 Sulphides (McClenaghan, in prep.)
(wt %)								
SiO_2	XRF-F (0.01)	56.50	55.00	67.40	59.40	64.20	60.50	5.7
TiO_2	XRF-F (0.01)	0.40	0.89	0.28	0.36	0.89	0.56	0.04
Al_2O_3	XRF-F (0.01)	20.30	21.00	14.00	20.10	14.80	18.04	1.9
$Fe_2O_3^*$	XRF-F (0.01)	3.34	5.95	3.19	3.78	6.24	4.50	53.9
MnO	XRF-F (0.01)	0.22	0.29	0.29	0.09	0.14	0.21	0.23
MgO	XRF-F (0.01)	4.62	2.22	3.24	4.24	3.09	3.48	0.99
CaO	XRF-F (0.01)	2.78	1.92	2.24	0.17	1.45	1.71	1.3
Na_2O	XRF-F (0.01)	0.39	1.59	0.51	1.79	2.01	1.26	-0.03
K_2O	XRF-F (0.01)	4.57	4.06	3.16	4.87	3.06	3.94	0.48
P_2O_5	XRF-F (0.01)	0.15	0.14	0.10	0.05	0.18	0.12	0.05
LOI	XRF-F (0.01)	7.00	5.05	5.00	4.05	3.30	4.88	
S								45.3
(ppm)								
Ag	ICP (0.1)	0.7	0.9	0.6	0.6	0.3	0.62	39
As	INAA (1.0)	0.0	9.0	25.0	0.0	3.0	7.40	3000
Au (ppb)	INAA (2.0)	-2.0	7.0	5.0	5.0	-2.0	2.60	297
B	ICP (1.0)	50.0	65.0	-10.0	76.0	-10.0	34.20	
Ba		860.0	745.0	810.0	801.0	411.0	725.40	540
Be	ICP (1.0)	5.0	4.0	4.0	6.0	3.0	4.40	0.6
Bi	ICP-MS (0.5)	2.0	1.0	1.0	-1.0	-1.0	0.40	100
Br	INAA (1.0)	3.0	1.0	3.0	3.0	2.0	2.40	-0.05
Cd								29
Co	ICP (1.0)	3.0	12.0	3.0	3.0	17.0	7.60	13
Cr	INAA (2.0)	8.0	44.0	5.0	7.0	71.0	27.00	40
Cs	INAA (0.5)	8.0	6.0	7.0	5.0	3.0	5.80	1.3
Cu	ICP (0.5)	6.0	21.6	6.3	3.1	2.8	7.96	1200
Ga	ICP-MS (1.0)	31.0	31.0	23.0	31.0	21.0	27.40	3.4
Hf	INAA (2.0)	11.0	8.0	8.0	10.0	6.0	8.60	0.79
Hg (ppb)	WET	-5.0	41.0	105.0	-5.0	-5.0	26.20	3
Li	ICP (1.0)	85.0	51.0	61.0	62.0	31.0	58.00	
Nb	XRF (2.0)	21.0	19.0	16.0	21.0	18.0	19.00	2.2
Ni	ICP (1.0)	3.0	21.0	7.0	2.0	33.0	13.20	-10
Pb	ICP (2.0)	5.0	-2.0	29.0	-2.0	-2.0	5.60	5300
Rb	XRF (2.0)	225.0	190.0	173.0	189.0	125.0	180.40	-15
Sb	INAA (1.0)	0.0	5.0	3.0	0.0	1.0	1.80	160
Sc	ICP (1.0)	12.0	15.0	9.0	12.0	12.0	12.00	1.3
Sn	XRF (2.0)	23.0	16.0	6.0	14.0	10.0	13.80	3.2
Sr		188.0	172.0	163.0	80.0	56.0	131.80	61
Ta	INAA (0.5)	2.0	1.0	1.0	2.0	1.0	1.40	-0.2
Th	INAA (2.0)	45.0	24.0	30.0	37.0	12.0	29.60	2.3
U	INAA (1.0)	4.5	8.1	2.1	0.5	2.9	3.62	1.4
V	ICP (2.0)	12.0	102.0	10.0	8.0	107.0	47.80	-0.5
W	INAA (1.0)	-1.0	-1.0	2.0	3.0	2.0	1.00	3
Y	ICP-MS (1.0)	78.0	73.0	64.0	92.0	35.0	68.40	10
Zn	ICP (0.5)	49.6	100.0	43.6	52.5	39.5	57.04	8260
Zr	XRF (1.0)	348.0	284.0	247.0	304.0	214.0	279.40	24
La	ICP-MS (1.0)	71.50	74.90	60.70	63.20	43.60	62.78	6.5
Ce	ICP-MS (1.0)	170.00	158.00	139.00	147.00	92.10	141.22	10
Pr	ICP-MS (1.0)	21.00	19.00	17.00	17.00	11.00	17.00	1.9
Nd	ICP-MS (1.0)	78.80	71.30	66.60	68.50	41.80	65.40	7.1
Sm	ICP-MS (1.0)	22.20	18.30	18.90	21.50	11.30	18.44	1.4
Eu	ICP-MS (0.5)	1.00	1.89	0.74	0.64	1.88	1.23	0.26
Gd	ICP-MS (1.0)	16.00	14.30	14.50	17.40	8.50	14.14	1.8
Tb	ICP-MS (1.0)	2.50	2.30	2.20	3.00	1.20	2.24	0.31
Dy	ICP-MS (1.0)	14.90	14.40	13.50	18.30	7.30	13.68	1.8
Ho	ICP-MS (0.5)	3.11	2.93	2.74	3.86	1.41	2.81	0.34
Er	ICP-MS (1.0)	9.00	7.70	7.40	10.90	3.90	7.78	0.92
Tm	ICP-MS (1.0)	1.30	1.10	1.00	1.60	0.60	1.12	0.14
Yb	ICP-MS (1.0)	8.20	6.50	6.40	9.80	3.90	6.96	0.85
Lu	ICP-MS (0.5)	1.24	0.88	0.88	1.39	0.55	0.99	0.12

Notes: Analyses were carried out at XRAL, Don Mills, Ontario.
INNA–neutron activation, ICP–inductively coupled plasma, ICP-MS–inductively coupled plasma/mass spectrometry, XRF–X-ray flouresance; WET–wet chemistry techniques.

Table 2. Lithogeochemical Analyses of Shale Samples from Drill Core at the Nine Mile Brook Massive Sulphide Occurrence, and Boucher Brook Formation Type Section

Sample Name Rock Type	Method (detection limit)	NM95-7-11.1 shale (HW)	NM95-7-67.3 phyllite (FW)	NM95-4-63.3	NM95-4-66.7	NM95-4-69 McClenaghan (in prep.)	Avg. Shale (Nine Mile Brook)	JP96081	JP96082	JP96083	JP96084	JP96085 Langton (1997), Boucher Brook type section	Boucher Brook Avg.
(wt %)													
SiO_2	XRF-F (0.01)	56.10	54.60	57.40	60.30	61.30	57.94	60.69	57.61	57.07	53.59	57.67	57.33
TiO_2	XRF-F (0.01)	0.82	0.90	0.46	0.68	0.44	0.68	0.87	1.01	1.04	0.92	0.87	0.94
Al_2O_3	XRF-F (0.01)	16.50	16.80	14.70	17.60	16.80	17.28	19.97	19.42	19.13	20.20	17.86	19.32
Fe_2O_3*	XRF-F (0.01)	11.50	11.40	9.60	6.90	4.60	8.84	6.06	8.51	7.95	10.46	10.91	8.78
MnO_2	XRF-F (0.01)	1.45	0.62	0.27	0.15	0.09	0.52	0.06	0.12	0.08	1.27	0.14	0.33
MgO	XRF-F (0.01)	1.98	2.09	5.52	3.51	4.16	3.46	1.09	2.68	1.99	1.42	3.87	2.21
CaO	XRF-F (0.01)	0.50	0.51	1.54	0.49	0.58	0.72	0.04	0.08	0.04	0.53	0.35	0.21
Na_2O	XRF-F (0.01)	0.27	0.96	0.70	1.70	0.70	0.87	0.23	0.90	1.15	0.54	0.48	0.66
K_2O	XRF-F (0.01)	3.54	3.65	2.35	3.21	3.97	3.34	4.91	4.37	4.49	4.54	2.56	4.17
P_2O_5	XRF-F (0.01)	0.26	0.22	0.25	0.17	0.14	0.21	0.08	0.09	0.11	0.39	0.26	0.19
LOI	XRF-F (0.01)	7.10	6.30				2.68						
(ppm)													
Ag	ICP (0.1)	1.3	1.3	0.3	0.4	0.2	0.70						
As	INNA (1.0)	74.0	61.0	230.0	140.0	34.0	107.80						
Au (ppb)	INNA (2.0)	-2.0	-2.0	-2.0	-2.0	-2.0	-2.00						
B	ICP (1.0)	87.0	98.0				37.00						
Ba		686.0	1230.0	2800.0	2000.0	3200.0	1983.60	500.0	471.0	534.0	694.0	620.0	563.80
Be	ICP (1.0)	5.0	5.0	6.0	4.7	6.6	5.86						
Bi	ICP-MS (0.5)	-1.0	-1.0	1.1	1.1	1.4	0.32						
Br	INNA (1.0)	3.0	2.0	-0.5	2.9	-0.5	1.38						
Co	ICP (1.0)	18.0	26.0	21.0	21.0	7.0	18.60	5.0	5.0	5.0	42.0	27.0	16.80
Cr	INNA (2.0)	76.0	87.0	28.0	63.0	20.0	54.80	95.0	98.0	99.0	106.0	91.0	97.40
Cs	INNA (0.5)	6.0	7.0	6.3	7.6	11.0	7.58						
Cu	ICP (0.5)	36.6	46.3	75.0	58.0	20.0	47.18						
Ga	ICP-MS (1.0)	24.0	26.0	25.0	27.0	30.0	26.40						
Hf	INNA (2.0)	4.0	5.0	6.6	6.5	9.3	6.28						
Hg (ppb)	WET	41.0	26.0				13.40						
Nb	XRF (2.0)	16.0	20.0	22.0	20.0	23.0	20.20	19.0	19.0	20.0	18.0	18.0	18.80
Ni	ICP (1.0)	56.0	53.0	54.0	43.0	14.0	44.00	16.0	38.0	24.0	53.0	53.0	36.80
Pb	ICP (2.0)	21.0	7.0	58.0	60.0	61.0	41.40	7.5	29.0	82.0	68.0	139.0	65.10
Rb	XRF (2.0)	152.0	160.0	100.0	130.0	160.0	144.40	242.0	201.0	202.0	203.0	105.0	190.60
Sb	INNA (1.0)	3.0	7.0	16.0	15.0	6.0	9.40						
Sc	ICP (1.0)	15.0	16.0	12.0	15.0	13.0	14.20						
Sn	XRF (2.0)	16.0	12.0	5.2	6.4	8.3	9.58						
Sr		79.0	92.0	83.0	56.0	55.0	73.00	42.0	17.0	18.0	119.0	86.0	58.40
Ta	INNA (0.5)	1.0	1.0	1.3	1.3	1.4	1.20						
Th	INNA (2.0)	13.0	12.0	25.0	23.0	35.0	21.60	14.0	16.0	15.0	14.0	18.0	15.40
U	INNA (1.0)	3.1	3.0	2.0	4.8	3.7	3.32	5.0	5.0	10.0	5.0	12.0	7.40
V	ICP (2.0)	122.0	154.0	28.0	89.0	19.0	82.40	108.0	138.0	189.0	130.0	129.0	138.80
W	INNA (1.0)	4.0	4.0	9.0	-1.0	4.0	4.00						
Y	ICP-MS (1.0)	34.0	32.0	85.0	57.0	78.0	57.20	26.0	34.0	31.0	35.0	31.0	31.40
Zn	ICP (0.5)	111.0	105.0	372.0	479.0	136.0	240.60	41.0	88.0	62.0	97.0	113.0	80.20
Zr	XRF (1.0)	142.0	153.0	240.0	230.0	320.0	217.00	127.0	141.0	154.0	150.0	135.0	141.40
La	ICP-MS (1.0)	42.10	48.00	68.00	59.00	77.00	58.82	83.00	64.00	30.00	30.00	30.00	43.40
Ce	ICP-MS (1.0)	95.10	110.00	160.00	130.00	160.00	135.02	110.00	110.00	99.00	152.00	124.00	119.00
Pr	ICP-MS (1.0)	10.00	11.00	20.00	15.00	23.00	15.80						
Nd	ICP-MS (1.0)	40.30	43.70	72.00	55.00	84.00	59.00	30.00	30.00	30.00	62.00	30.00	36.40
Sm	ICP-MS (1.0)	10.70	11.40	14.00	10.00	15.00	12.22						
Eu	ICP-MS (0.5)	1.74	1.49	1.60	1.40	0.83	1.41						
Gd	ICP-MS (1.0)	8.70	8.30	14.00	11.00	15.00	11.40						
Tb	ICP-MS (1.0)	1.20	1.20	2.30	1.60	2.40	1.74						
Dy	ICP-MS (1.0)	7.60	7.00	14.00	10.00	14.00	10.52						
Ho	ICP-MS (0.5)	1.44	1.35	2.70	2.10	2.90	2.10						
Er	ICP-MS (1.0)	4.10	3.80	7.20	5.80	7.90	5.76						
Tm	ICP-MS (1.0)	0.60	0.50	0.99	0.80	1.10	0.80						
Yb	ICP-MS (1.0)	3.80	3.40	6.50	5.60	7.30	5.32						
Lu	ICP-MS (0.5)	0.55	0.49	0.87	0.71	94.00	19.32						

Notes: Analyses were carried out at XRAL, Don Mills, Ontario.
INAA–neutron activation; ICP–inductively coupled plasma; ICP-MS–inductively coupled plasma/mass spectrometry; XRF–X-ray flouresence; WET–wet chemistry techniques

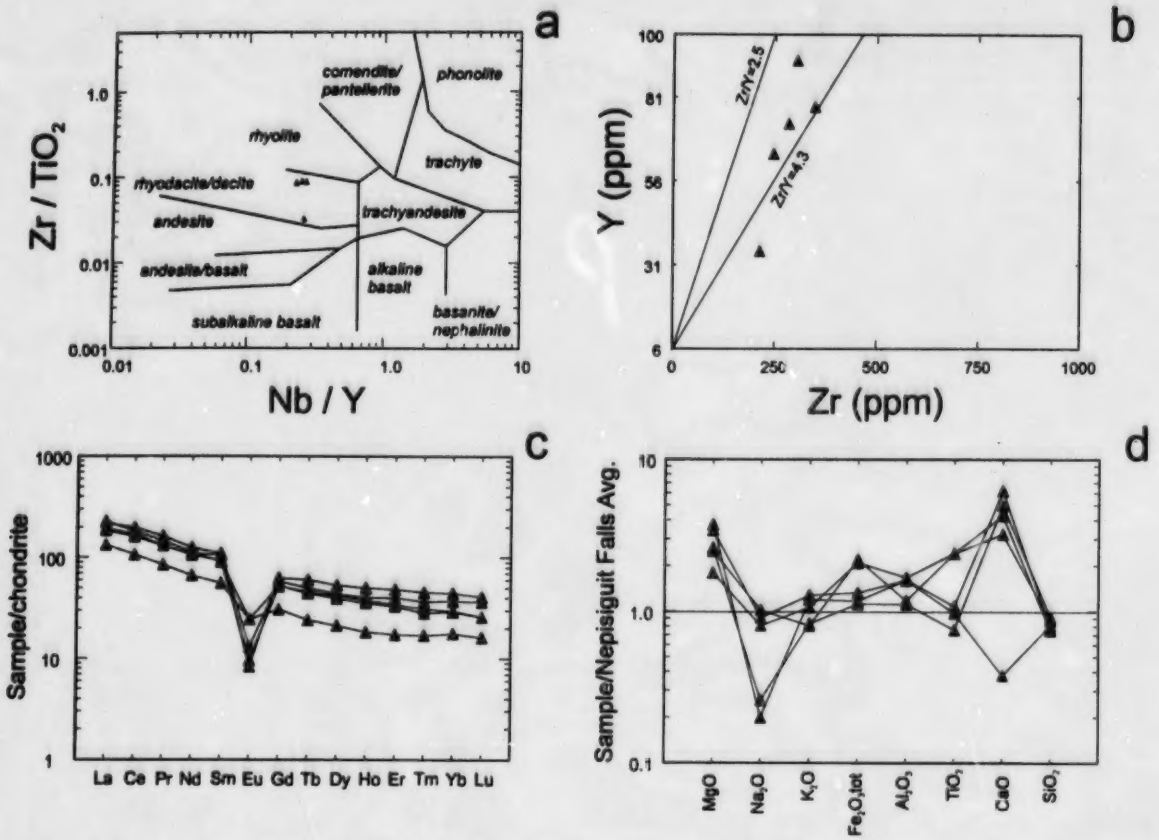

Figure 8. Lithogeochemical discrimination diagrams for felsic volcanic rocks from the Nine Mile Brook occurrence. (a) Zr/TiO_2 versus Nb/Y diagram of Winchester and Floyd, 1977). (b) Zr versus Y discrimination diagram (modified from Rogers and van Staal 1996). (c) Chondrite-normalized rare-earth-element data, normalization factors from Taylor and McLennan (1985). (d) major-element data normalized to the average value of the Nepisiguit Falls Formation (Langton and McCutcheon 1993).

Rare-earth-element variations for the felsic volcanic rocks from the Nine Mile Brook occurrence are plotted on a chondrite-normalized spider diagram (Figure 8c). These samples show light rare-earth-element enrichment and a negative Eu anomaly (related to feldspar crystallization), typical of early-erupted felsic volcanic rocks in the Bathurst Mining Camp.

The major-element data for the felsic rocks are normalized to the average unaltered Nepisiguit Falls rhyodacite of Langton and McCutcheon (1993), and show the relative increase or depletion for the various major-element oxides (Figure 8d). The Nepisiguit Falls average was chosen as a normalization factor because no average data for the Spruce Lake Formation has been published, and because the Spruce Lake and Nepisiguit Falls formations are coeval (470 Ma) and are thought to have erupted under similar conditions. Relative to the average unaltered Nepisiguit Falls Formation, MgO is enriched in the Nine Mile Brook rocks (2.0–4.25 wt. %), and is probably related to chlorite formation during hydrothermal alteration. Some of the more intensely altered rocks show strong Na depletion and Ca enrichment, which is also consistent with hydrothermal alteration.

Sedimentary rocks

Two samples of shale were collected from drill hole 95-7, one from either side of the massive sulphide lens, and one sample from drill hole 95-88. Three other samples of sedimentary rock immediately adjacent to the sulphide lens were collected from diamond-drill hole 95-4 (McClenaghan, in prep.) The results of the chemical analyses of these samples are presented in Table 2. For comparison, five samples from the Boucher Brook Formation type section (Langton 1997), which is located approximately 1500 m north-northwest of the Nine Mile Brook occurrence (Figure 1), are also presented in Table 2.

Table 2 shows that there is very little difference in major- and/or trace-element chemistry between the shale sample from the hanging wall (sample 95-7-11.1) and the footwall (sample 95-7-67.3). The Nine Mile Brook samples differ slightly from the samples collected from the Boucher Brook type section (Langton 1997). In particular, shale samples from the Nine Mile Brook occurrence are higher in CaO, MgO, Ba and Na_2O, whereas the Boucher Brook samples have higher K_2O.

A chondrite-normalized rare-earth-element (REE) spider diagram for shale samples from the Nine Mile Brook occurrence is presented in Figure 9a. As is evident from this diagram, the Σ REE for the Nine Mile Brook shale samples is higher than the North American Shale Composite (NASC). Unlike the NASC, the Nine Mile Brook samples have negative Eu anomalies that are consistent with a high volcanic component / source area.

An Al/(Al+Fe+Mn) versus Fe/Ti discrimination diagram (Bostrom 1973), can be used to determine the degree of hydrothermal input relative to terrigenous input in a marine sediment (Figure 9b). As is evident from this diagram, shale samples from the study area compare closely to the shale samples from the Boucher Brook type section, and most have only a slightly greater hydrothermal component than the North American Shale Composite of Gromet *et al.* (1984).

DISCUSSION

Evidence presented above demonstrates that the massive sulphide mineralization at Nine Mile Brook occurs in a zone of intense deformation. What is not clear, is the position of this occurrence with respect to the predeformational stratigraphy of the California Lake Group. Two interpretations, based on the tectonostratigraphic cross section in Figure 6, are presented below.

Scenario 1

The Nine Mile Brook mineralization was originally deposited within or possibly at the base of the Spruce Lake Formation, i.e., a position similar to that of the Caribou deposit (Thomas *et al.* 2000 and references therein). This is supported by the intimate association of Spruce Lake felsic volcanic rocks with the sulphide lens.

A deep hole drilled by Inmet Mining Corporation (DDH WL-03) to test the main showing at depth (> 300 m below surface) failed to encounter massive sulphide mineralization (Figure 3). Interestingly, felsic volcanic blocks that are common in the mélange at surface were not found at depth. Although massive sulphide mineralization was not intersected, elevated base metal values were encountered near

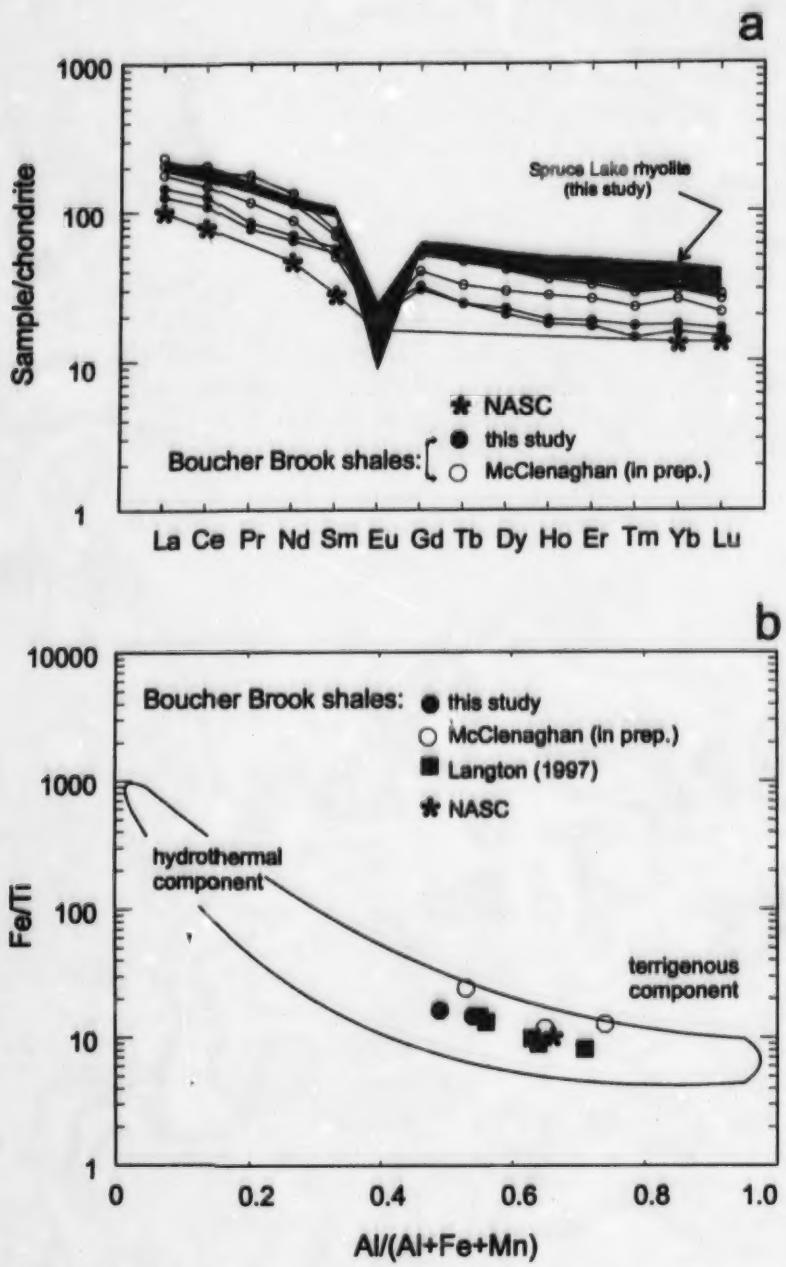

Figure 9. Lithogeochemistry of sedimentary rocks collected from the Nine Mile Brook volcanogenic massive sulphide occurrence. (a) Chondrite-normalized spider diagram. Normalization factors are from Nakamura (1974). (b). Al/Al+Fe+Mn versus Fe/Ti discrimination diagram (modified from Bostrom 1973), for sedimentary rocks from the Nine Mile Brook occurrence. For both figures, NASC is the North American Shale Composite (Gromet *et al.* 1984).

the bottom of the hole. A 2.8 m intersection between 461.8 and 464.6 m returned assays of 140 ppm Cu, 1650 ppm Zn, and 27 ppb Au, whereas a 1.5 m intersection (486.1 to 487.6 m), returned 1580 ppm Cu, 800 ppm Zn and 50 ppb Au (MacDonald 1997).

Unfortunately, the lack of felsic rocks at depth indicates that the mélange horizon may be closing with depth (Figure 6). If this is true, there is not much hope for finding additional mineralization at depth in the vicinity of the Nine Mile Brook occurrence. However, the doubly-plunging nature of the F_2 folds does allow for the potential of finding additional mineralization along strike from known mineralization.

Scenario 2

Alternatively, the Nine Mile Brook mineralization could have formed at a higher stratigraphic level, i.e., from the lower thrust sheet, near the top of the Boucher Brook Formation. This scenario is supported by the Zn–Cu-rich nature of the sulphide lens, which is typical of mafic-volcanic-associated deposits (Franklin *et al.* 1981), and atypical of most other Bathurst Mining Camp deposits that tend to have Zn > Pb >> Cu. To date, no volcanogenic massive sulphide deposits have been identified at this stratigraphic level in the camp. However, roughly coeval Fournier Group rocks in the Elmtree Inlier north of the camp do host Cyprus-type Cu–Zn sulphide mineralization.

The juxtaposition of Spruce Lake felsic volcanic blocks with the Nine Mile Brook occurrence would seem to negate the possibility of mineralization forming in the Boucher Brook Formation, i.e., mineralization is more likely synchronous with rather than post-dating felsic volcanism. However, the spatial relationship between the felsic volcanic and sedimentary rocks could simply reflect tectonic mixing along a thrust zone (i.e., the sulphide lenses may simply be additional exotic blocks like the rhyolite blocks in the mélange zone).

The absence of iron formation or siliceous exhalite in and around the Nine Mile Brook occurrence indicates that it either never formed or was tectonically dismembered and removed. The former is preferred if assignment to a lower Spruce Lake stratigraphic level is assumed. This is because iron formation has not been reported for any other deposits in the California Lake Group, with the exception of the Restigouche deposit, which has a siliceous tuff/exhalite in the structural hanging wall (Gower 1996).

CONCLUSIONS

1. The discontinuous and discordant nature of the sulphide lens, its relationship with matrix-supported pyritized rhyolite blocks, and the presence of dismembered sedimentary rock fragments in a black shale mélange indicate that the occurrence lies within a tectonically disrupted zone. This is supported by the presence of regional-scale thrust faults immediately south of the mineralization.

2. Rhyodacitic rocks of the Spruce Lake Formation in the Mud Lake Antiform and felsic volcanic blocks in the mélange at the Nine Mile Brook occurrence are similar in terms of trace-element chemistry. In particular, rocks in both of these areas have low (<4.3) Zr/Y ratios, which are unique to the Spruce Lake Formation.

   The intense degree of hydrothermal alteration and pyritization in felsic rocks of the Mud Lake Antiform and at the Nine Mile Brook occurrence suggests that these rocks may have been part of the same or

similar hydrothermal system. Therefore, these two packages of rocks cannot be greatly separated by a tectonic break as indicated by van Staal (1994).

3. The predeformational stratigraphic position of the Nine Mile Brook occurrence was most likely within interbedded fine-grained sedimentary rocks at or near the base of the Spruce Lake Formation.

4. Sulphide mineralization at Nine Mile Brook consists of high-grade Zn + Cu >> Pb, which is atypical of Bathurst Mining Camp volcanogenic massive sulphide deposits. Tectonostratigraphic reconstruction suggests low potential for finding additional base-metal sulphides in the immediate vicinity of the Nine Mile Brook occurrence, but the possibility of discovery along strike to the west or north cannot be ruled out.

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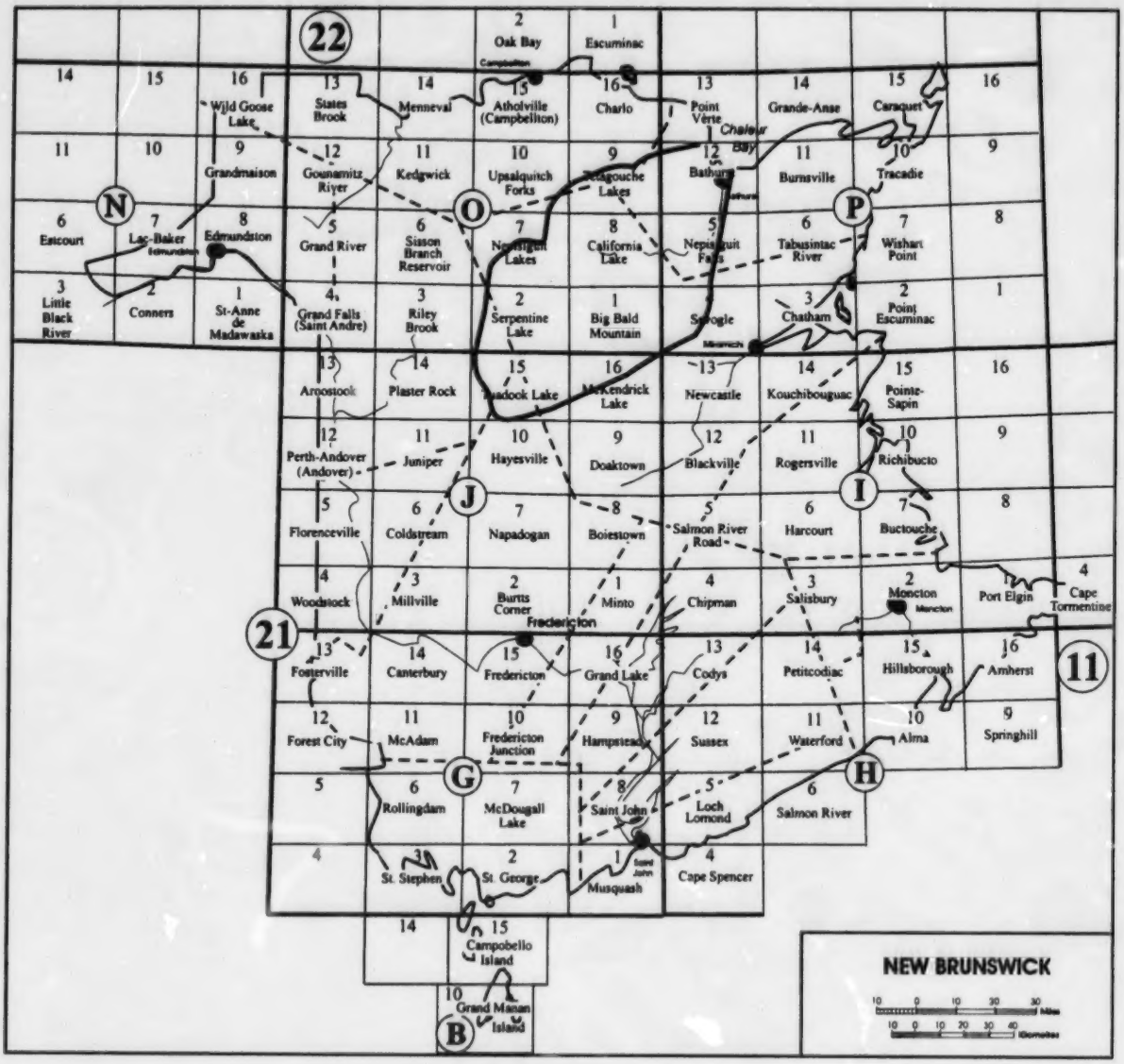

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Conversion Factors:
Imperial and International System of Units (SI)

The following multipliers should be used to convert imperial units to SI units or SI units to imperial units:

CONVERSION FROM SI TO IMPERIAL			CONVERSION FROM IMPERIAL TO SI		
SI Unit	*Multiply by*	*Gives*	*Imperial Unit*	*Multiply by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0 404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.32 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE: Conversion factors in bold type are exact.

SOURCE: Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by The Mining Association of Canada in cooperation with the Coal Association of Canada.